BIOLOGY

GENERAL AND MEDICAL

BY

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TO MY MOTHER

who first interested me in the

LIVING THINGS

and taught me to marvel

at the

WORKS OF GOD

PREFACE.

In preparing this book it has been the purpose of the author to acquaint his readers with the peculiar nature and interesting reactions of "Living Substance"; to help him trace it to its probable, though unknown, beginnings and follow it through its multifarious differentiations to its highest complexity.

In so far as this has been accomplished, the work is a *General Biology*. But more has been attempted, for the problems have been so considered as to show that man is no separate entity, apart from the general world of living things, but is a unit in the general scheme of things and subject to the same laws that apply throughout the universe.

Inasmuch as many of the subjects treated are of importance to students contemplating future medical studies, and inasmuch as all of them are of interest and importance to students of medicine and physicians, the work may, with justification, claim to be a *Medical Biology*.

All of the problems of medical science are in a sense biological, and many of the problems of biological science medical. Medical science is, in fact, a branch of biology and should be studied as such.

Each chapter treats of some subject or subjects upon which the pen would gladly linger and upon which a volume might be written, and professional biologists will, no doubt, be disappointed at the brief treatment their pet theories receive as well as astonished at the space devoted to other, and to them less important,

matters, but this is the inevitable result of the particular point of view of the author.

Nearly all of the subjects treated are of controversial nature, but that is the present state of biological science. Attempts to crystallize incomplete information into laws lead to theory rather than to fact, and the subject passes from theory to theory in search of the fact. This explains why the consideration of certain subjects may lead the reader to a final interrogation point or may end without a personal expression by the author in favor of one or the other side of the question.

It is hoped that the problems of Blood-relationship, Infection, Immunity, Parasitism, Inheritance, Mutilation, Regeneration, Grafting, and Senescence, which have been presented at greater length than in other writings upon Biology, may be useful to the reader.

It is hoped that the writing will not be found too technical to be beyond the comprehension of any intelligent reader, though it must be admitted that some acquaintance with the sciences will be of decided advantage to him.

The author expresses his sincere thanks to his friend and colleague, Professor Charles H. Shaw, A.M., Ph.D., for many valuable suggestions and criticisms.

PHILADELPHIA, PA. JOSEPH McFARLAND.

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BIOLOGY: GENERAL AND MEDICAL.

CHAPTER I.

THE COSMICAL RELATIONS OF LIVING MATTER.

To study the problems of life apart from their cosmical relations is to lose much of their significance. It is only by an appreciation of the endless changes—integrations and disintegrations—that pervade the universe that one comes to realize that those qualities by which we recognize living substance more or less closely correspond to the qualities of all substance, and those forces by which it is animated to those forces by which the universe itself is controlled.

All the demonstrations of physics arrive at one conclusion: that the universe consists of matter that is indestructible, controlled by forces that are persistent. Beyond this it is not in the power of the human intellect to penetrate.

We know nothing and probably never can know anything of the origin of matter or force, and are obliged to content ourselves, as our antecedents have done, with the knowledge that both exist, and that we can only recognize the existence of force as it influences matter, and only know matter as it is affected by force.

The planet upon which we live consists of matter in a highly differentiated state which the chemists are able to resolve into a certain number of forms so stable as not to be susceptible of further analysis, and therefore called

"*elements.*" Astronomy, however, shows us that the primitive form of matter is gaseous and leads us to infer that it is only through prolonged integration and differentiation that the "elements" of the chemist have been produced.

Of the cosmical theories the *nebular hypothesis* of Kant and Laplace seems to be the one best suited to the present thought, in spite of the more recent theories that the heavenly bodies including our planet have been formed by the coming together of ice-cold meteors, or by gradual accretion through the continued accession of cold planetary matter in space.

According to the "*nebular hypothesis*" space is filled with matter in every conceivable state of integration and disintegration, its most primitive form being that of gaseous vapor in a state of incandescence. According to fixed laws, the forces of the universe act upon this gaseous vapor until it gradually collects more and more locally to form nebulous masses such as can be seen in various of the constellations. Through infinite time the nebulæ become more and more condensed until, in obedience to the continually operating forces, they begin to rotate more and more uniformly, their vaporous particles to approximate more and more closely, and finally to coalesce to form fiery masses whose progressive integration passes from the gaseous to the fluid and finally to the solid state, and the formation of definite heavenly bodies.

When the forces acting upon the nebulous matter are uniform a single body may be produced, but when they are conflicting several may be formed, the smaller rotating about the larger in definite systems. The smaller bodies of the system are subject to the most rapid subsequent changes, so that in any planetary system bodies in all stages may be observed. This is, for example, supposed to be the state of our own solar system, in which the sun is still a gaseo-liquid incandescent body, some of the larger planets semi-solid, the

earth solid and cool upon the surface, and its moon probably cold throughout. It is during the cooling and integration of such heavenly bodies that the differentiation of the component matter takes place. As this progresses, a multitude of combinations appear for a time, transform to new combinations, and so continue through an indefinite series of transformations, eventuating in things constituted as we now know them.

During these transformations certain substances appear whose stability constitutes the foundations of chemistry. Some of these occur in the elementary form, *i.e.*, incapable of analysis into simpler forms, but more frequently they occur in combinations from which they can be liberated by artificial means and thus reduced to the elementary form. Some elementary forms combine with one another easily, others with difficulty. Some of the combinations are so unstable as to tend to break apart rather than to persist. Thus, among the chemical components of our planet we find a certain number, combined to form the rocks and soil, subject to little change, and to that only under peculiar circumstances, while upon the surface of the earth we find a small quantity of matter composed of elements entering into loose combinations and tending to perpetual change. The substances we call living. are included among these ever-changing combinations.

The most evanescent of these compounds comprise a group known as "colloids," many of which have a molecular composition, ascending in complexity until among the proteins we find "*protoplasm*" with a composition not yet definitely determined, but embracing O, H, C, N, S, and in some cases P.

This substance, protoplasm, constitutes the basis of living matter.

CHAPTER II.

THE ORIGIN OF LIFE.

The early philosophers of all nations referred human existence directly to our parents and indirectly to the gods, although it seemed to them a simple matter that the lower forms of life should come into being *de novo*. Belief in the spontaneous generation of the lower forms of life accentuated as philosophy slowly separated itself from religion. Greek philosophy is replete with expressions regarding the spontaneous generation of the lower forms of life, and the idea persisted through the middle ages to become a matter of paramount interest during the latter half of the nineteenth century.

The most superficial consideration of the subject is sufficient to show that among the ancients it was unfamiliarity with the lowly forms of life that led to such a notion, but more modern writers seem to have been led astray through the expansion of knowledge following the invention of the microscope which introduced them to a world of newer and simpler forms of life, and thus changed the problem. Thus, one possessed of the most elementary information upon natural history might scout the idea that such complexly organized beings as mice could be spontaneously generated, though the same difficulties might not at first stand in the way of conceiving that amœba or bacteria might be.

As the conception of spontaneous generation has undergone modifications consistent with the evolution of knowledge in general, it is worth while to review the subject and see what it has meant, and what it now means to those who, is spite of all the evidence at hand, continue to adhere to it.

Among the ancient Greeks, Anaximander believed that animals arose through the stimulating action of moisture. Empedocles believed that all living things arose spontaneously. Aristotle, whose familiarity with natural history was much broader, does not subscribe to so general a view, but asserts that "*sometimes* animals are formed in putrefying soil, sometimes in plants, and sometimes in the fluids of other animals."

Virgil in Book IV of the "Georgics" describes the spontaneous generation of bees in the following language:

"First, a space of ground of small dimensions, and narrowed for this purpose is chosen; this they cover in with the tiling of a narrow roof and with confining walls, and add four openings with a slanting light turned toward the four points of the compass. Then a bullock, just arching his horns upon his forehead of two years old, is sought out; whilst he struggles fiercely, they close up both his nostrils and his mouth; and when they have beaten him to death, his battered carcass is macerated within the hide which remains unbroken. Then they leave him in the pent-up chamber, and lay under his sides fragments of boughs, thyme, and fresh casia. This is done when first the zephyrs stir the waves, before the meadows blush with new colors, before the twittering swallow suspends her nest upon the rafters. Meanwhile, the animal juices, warmed in the softened bones, ferment: and living things of wonderful aspect, first devoid of feet, and in a little while buzzing with wings, swarm together, and more and more take to the thin air, till they burst away like a shower poured down from summer clouds; or like an arrow from the impelling string, when the swift Parthians first begin to fight."

Ovid, in his poetic account of the Pythagorean philosophy, commits its followers to belief in many forms of spontaneous generation:

"By this sure experiment we know
That living creatures from corruption grow:
Hide in a hollow pit a slaughtered steer,
Bees from his putrid bowels will appear,
Who like their parents, haunt the fields and
Bring their honey-harvest home, and hope another spring.
The warlike steed is multiplied we find,

To wasps and hornets of the warrior kind,
Cut from a crab his crooked claws and hide
The rest in earth, a scorpion thence will glide,
And shoot his sting; his tail in circles toss't
Refers the limbs his backward father lost;
And worms that stretch on leaves their filmy loom
Crawl from their bags and butterflies become.
The slime begets the frog's loquacious race;
Short of their feet at first, in little space
With arms and legs endued, long leaps they take,
Raised on their hinder parts and swim the lake,
And waves repel; for nature gives their kind,
To that intent, a length of legs behind."

During the middle ages Cardan, in 1524, declared that water engendered fishes, and that many animals spring from fermentation. Van Helmont published special directions for the experimental generation of mice. Kircher describes and figures certain animals which he declares were formed, under his own eyes, through the transforming influence of water upon the stems of plants.

Children and ignorant persons still believe in the spontaneous generation of many living things and in the country districts many persons of otherwise good judgment believe that frogs and mosquitoes arise spontaneously in marshes, while the belief that a horse-hair placed in a water trough will be transformed to a thread-like worm, is widespread.

No one seems to have doubted that maggots were spontaneously developed in putrid meat until Redi became interested in the subject about 1680 and disproved it by a simple scientific demonstration:

"Watching meat in its passage from freshness to decay, prior to the appearance of maggots, he invariably observed flies buzzing around the meat and frequently alighting upon it. The maggots, he thought, might be the half-developed progeny of these flies. Placing fresh meat in a jar covered with paper, he found that although the meat putrefied in the ordinary way it never bred maggots, while meat in open jars soon swarmed with them. For

the paper he substituted fine gauze through which the odor of the meat could rise. Over it the flies buzzed, and upon it they laid their eggs, but the meshes being too small to permit the eggs to fall through, no maggots generated in the meat, they were, on the contrary, hatched on the gauze. By such a series of experiments Redi destroyed the belief in the spontaneous generation of maggots in meat and with it many related beliefs."

But in 1683 a new phase of the subject was opened by the discovery of bacteria and many other minute forms of life by Leeuwenhoek, and many scientific men to whom the spontaneous generation of fishes, frogs, or insects appeared to be an absurdity, were misled into believing that what was not possible for these highly organized animals might easily take place among such minute and lowly organized beings as those of the new world disclosed by the microscope. It seemed as if the threshold of life had been reached.

To the intelligent mind of the present day, disembarrassed of erroneous beliefs, it will at once appear that the size of the creatures has no influence upon the merits of the case, for there are minute organisms visible only to the microscope that are as complexly formed as others that may be inches or even feet in length. To the idea of simplicity of structure the mind may yield; it does at first seem more reasonable that an organism of extreme simplicity might arise spontaneously than that one of great complexity could do so.

So it seemed to these early scientists. The microscopic organisms were small, and in many cases of no visible complexity, and with few exceptions they seemed satisfied to believe that they arose *de novo*. So, in the nineteenth century we find the same convictions regarding the spontaneous generation of the slightly known forms of microscopic life that had been held hundreds of years before regarding the slightly familiar small but complex animals, and thousands of years before regarding all living beings.

But as time went on the world of microscopic life was

scanned with improved instruments, and its population, when studied and classified, proved to be a miscellaneous one with varying structural complexity descending to a group so simple that correct classification seemed impossible. These ultimate beings appeared to be neither animals nor plants, and to have no definite place in the general scheme of living things. They were also innumerable, and their distribution apparently universal. Small wonder that it should have been thought a simple matter that what had so little structure, and was neither animal nor vegetable, could arise spontaneously under appropriate conditions. And, in passing, let it be noted that the appropriate conditions under which they appeared thus to arise were to be found in fermentation, putrefaction, and the discharges from morbid tissues—conditions that must recall once more the former beliefs about maggots, etc.

But there were some who conceived that the relationship between these minute entities and the conditions under which they were found were the reverse of those so generally accepted, and that instead of the minute organisms being generated through fermentative, putrefactive, and morbid conditions, the organisms initiated those conditions, increased in number as they progressed, and died out as they ceased.

Plenciz, a Viennese physician, greatly interested in the discoveries of Leeuwenhoek, was one of the first who assumed a causal relation between microorganisms and infectious diseases, and published this view as early as 1762. He also believed that decomposition only took place when the decomposable material became coated with a layer of organisms, and could only proceed as they increased and multiplied.

Needham, in 1749, firmly held to the belief that animalculæ generated spontaneously as a result of vegetative changes in the substances in which they were found. He maintained that the bacteria that were seen to appear around a grain of barley kept in a carefully covered

watch-glass, developed through changes incidental to its germination in the barley grain itself.

Spallanzani, some years later (1777), pointed out the slip-shod methods under which most of the so-called experiments had been performed, and supposed that he had proved spontaneous generation impossible by a new and improved technic. He filled flasks with various organic infusions, such as were supposed to be "biogenic," subjected the contents to thorough boiling, hermetically sealed them, and then placed them under what were supposed to be conditions favorable to the development of life, but always with negative results. Instead of carrying conviction with them, these experiments of Spallanzani were severely criticized by Treviranus on the ground that the atmosphere so essential to life had been excluded from the fluids. To overcome this objection, Spallanzani gently tapped his flasks so as to produce minute cracks through which air might enter. When this was done, life invariably appeared and decomposition occurred.

The problem remained in about the same state until Schultze in 1836 improved the method by which air was admitted to the flasks. He filled them but half full of putrescible fluids, boiled them thoroughly to destroy such life as they might already contain, and then daily sucked into them a certain quantity of air that passed through a series of bulbs containing concentrated sulphuric acid or strong alkalies by which any germs of life that might be in the air should be destroyed. The culture flasks were kept from May to August, air being passed into them daily, yet without the appearance of life or putrefaction in the contained fluid.

Schwann in the following year (1837) performed a similar experiment with the same result, passing the air admitted to the flasks through highly heated tubes instead of through acids and alkalies.

Schroeder and van Dusch, in 1854, discovered that if the mouth of the flask containing a putrescible fluid was

protected by a plug of cotton-wool through which an abundance of air could freely enter and exit, but by which it would be filtered, no life appeared in the contents.

The investigation was continued in 1861 by Pasteur, who showed that if the neck of a flask containing putrescible fluid was drawn out into a fine tube, bent down along the side of the flask, and then bent up again so as to form a V, it could be left open, after the contents of the flask had been thoroughly boiled, without danger of contamination from the outside air, which, entering through the

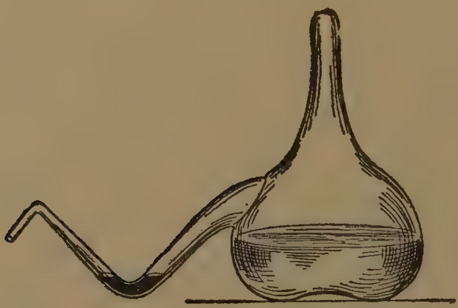

FIG. 1.—Flask used by Pasteur in his experiments upon the spontaneous generation of life. It was filled through the top which was then sealed. The contents, which consisted of putrescible fluid were then boiled, the side neck being open to permit the air to enter and exit. As the fluid cooled the side neck became closed by a few drops of water of condensation and prevented any germs of life from entering from without.

tubulature, would have any germs it might contain arrested by the drop of water of condensation that always collected in the angle of the tube.

Tyndall performed a most interesting series of experiments in which tubes were so placed as to project below the bottom of a closed chamber having a glass front and a glass window in each side. A rubber diaphragm was fixed in the roof through which a tube passed. Tyndall found that a ray of light passed through the side windows of the chamber was visible from the front because it was reflected from the dust particles suspended in the atmos-

phere of the box. After permitting the closed box to stand for a sufficient time, this dust was found to settle and the ray of light being passed through the side widow, finding nothing to reflect it, was no longer visible. When the contained atmosphere attained to this optical test of

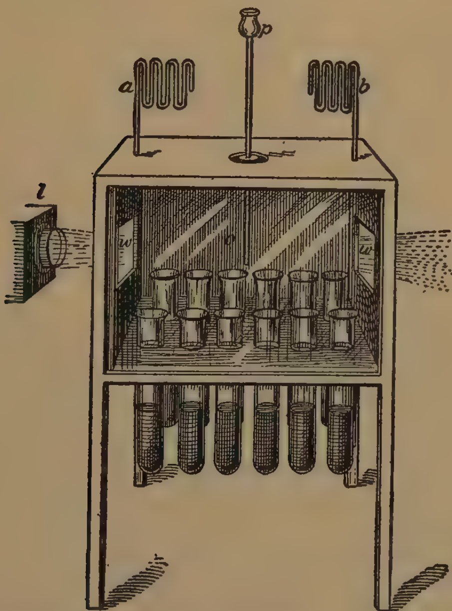

FIG. 2.—Tyndall's chamber for investigating the spontaneous generation of life. The front is of glass, as are the side windows, *w. w.* The optical test for the purity of the contained atmosphere is made by passing a powerful beam of light from the lamp, *l,* through the side windows. When the atmosphere contains no suspended particles, the tubes in the bottom are filled through the pipette, *p.c.* (*Tyndall.*)

purity, the tubes fixed in the bottom were cautiously filled with putrescible fluids through the tube in the rubber diaphragm. When filled, these tubes, the bottoms of which it will be remembered projected below the bottom of the chamber, were heated by applying a pan filled with hot brine, and their contents boiled briskly

for a time. When the chamber thus prepared was stood away, it was found that life rarely developed in the contents of the tubes and that no putrefaction took place. Thus Tyndall confirmed the work of Pasteur who in the meantime had been busily engaged in showing that there were "organized corpuscles" in the atmosphere—the "floating matter" of Tyndall—which when admitted to the infusions caused them to putrefy.

Cohn had engaged in morphological studies of the bacteria and other low forms of life, and had discovered that many of them, under appropriate conditions, pass into a resting or spore stage. In many of the rod-shaped organisms a spot appeared in the rod, grew larger and larger, and became surrounded by a capsule. While this was perfecting its development, the rod in which it formed began to degenerate and eventually set it free. Thus there came into being a minute body—a spore. Further study of the spores showed that they abounded in the atmosphere and that many of them could endure temperatures higher than that of boiling water. It now seems clear that it was through the entrance of such spores into the infusions, their endurance of the temperatures to which the fluids were subjected during boiling, and their subsequent germination that the appearance of life in the fluids was to be referred.

Thus Harvey's law *omne vivum ex ovo* which had long been accepted with reference to the higher beings became applicable to the lowest organisms in the modified form *omne vivum ex vivo,* and the doctrine of the spontaneous generation of life might be supposed to have received its death blow. The evidences thus collected were subsequently investigated by a great number of workers, by a great variety of methods, but with uniform results and at present almost every scientific mind is satisfied that life in the forms in which we now know it is never spontaneously evolved.

However, it remained to explain how, if all life descended from antecedent life, living things originally

made their appearance upon the earth, and to those working under the influence of this necessity the new doctrine *omne vivum ex vivo* was not adequate.

The primordial appearance of life is too important a matter to be entirely neglected; so we are led to inquire whether the simplest forms of life known to us are in any sense primitive or whether they may not, in fact, be highly developed compared to the primordial forms from which they may have descended.

Here we are confronted by several difficulties, one of the chief of which is that our conception of "life" and of "living substance" is based upon those forms with which we are familiar, and whose manifestations we are accustomed to describe as vital. It does not by any means follow that only such are "alive," but it is only of such that we speak as alive, and only such that we can through the limitations of our conception of the term prove to be so.

It may not be unprofitable to speculate with Bastian and especially with Burke whether there may not be other, unrecognized forms of life, whose extreme simplicity of structure prevents us from recognizing them, eternally coming into and going out of being, leaving no descendants behind them, the power of reproduction which we customarily look upon as an essential characteristic of life being, in fact, only characteristic of such forms as shall have already evolved to a certain point.

It is also of some interest to inquire whether the phenomena of life are so different from other chemical and physical phenomena as to make us place the customary gulf between the living and not living, or whether they are not but a part of those universal phenomena by which we can in a certain sense attribute life to the world, to the solar system or to the universe itself!

It is almost certain that life is no longer being generated, and that its original appearance upon this planet took place under circumstances no longer existing.

Thus, conditions of temperature during past periods of the world's evolution are believed by many to have been responsible for molecular combinations impossible at the present time. This is, however, conjectural, and not demonstrable. The chief argument in its favor is that all of our endeavors to see protoplasm come into being independently of antecedent life, have failed. We are thus obliged to conclude either that life never did arise spontaneously, or that it can no longer be generated spontaneously, or that we are at present unable to recognize the most primitive forms in which it occurs, being acquainted only with what are by comparison highly evolved forms.

References.

John Tyndall: "Floating Matter in the Air," N. Y., 1882.
J. Butler Burke: "The Origin of Life," N. Y., 1906.
H. Carlton Bastian: "The Modes of Origin of Lowest Organisms, etc.," Lond., 1871. "The Nature and Origin of Living Matter," Lond., 1905.

CHAPTER III.

THE CRITERIA OF LIFE.

Laying aside, for the present, all speculation as to the connecting links between the matter that we call *living*, and that which we declare to be *not living*, it becomes necessary to establish certain criteria by which the former be recognized. These distinctive properties have been formulated by Huxley as follows:

1. *Its chemical composition.*

The chemical composition of living substance is based upon a complex combination of O, H, N, and C known as protoplasm. It is a protein that is entirely unknown except as a product of living substance. Its exact composition is not determined because it is scarcely possible to study it apart from other elements by which and through which many of its functions are carried on. Chief among these are S and P.

2. *Its universal disintegration and waste by oxidation; and its concomitant reintegration by the intussusception of new matter.*

Life is accompanied by the manifestation of energy which implies combustion by oxidation, chemical disintegration of the complexly organized protoplasm, and its reduction into more highly oxidized but simple compounds, such as carbonic oxide and water. This would soon result in complete destruction of the protoplasm by analysis were it not within the power of the living substance to make good this loss as rapidly as it occurs.

When the living substance is young, the function of synthesis takes precedence over analysis and the organism is said to *grow*. This growth is, however, entirely

dissimilar to that of the growth of crystals, for example, where it takes place by accretion, or the addition of new matter to the surface, for it pervades the entire molecular structure of the protoplasm by the actual interposition of the new molecules between those already existing. When the function of synthesis keeps pace with that of analysis, growth ceases, and when analysis is more rapid than synthesis, life soon becomes extinct and the protoplasm breaks up into simpler and simpler compounds.

3. *Its tendency to undergo cyclical changes.*

The cyclical changes are largely incidental to the phenomena of reintegration. Coming into being through the activity of antecedent living substance, the living organism proceeds to increase its own substance, to dispose of that which is formed in excess of its own needs by detaching it in the form of new individuals, and finally when no longer able to maintain the equilibrium of reintegration to disintegration, ceasing to live and undergoing dissolution by destructive analysis, but being survived by descendants behaving in the same manner.

The successful application of these criteria for the recognition of life presuppose some acquaintance with the supposed living substance. One cannot immediately employ them for the determination of the living or not living character of any particular object picked up haphazard during a ramble through the country, for, should the objects in question be inactive forms of life, such as the seeds of plants, not only would confusion arise from the evident dissimilarity of chemical composition occasioned by the presence of the starch, cellulose, and wooden materials forming the most conspicuous structures of the seed, but one would be at a total loss in an attempt to immediately accord to the seed any molecular activity or cyclical changes. A superficial acquaintance with seeds is, however, sufficient to enable the investigator to apply the second and third criteria

without difficulty, for if warmth and moisture be supplied the living seed begins to germinate, a plant develops, and in the course of time new seeds identical with that under observation are formed. This shows that life presents various phases of activity and passivity, both of which must be taken into account in biological study. Unfamiliarity with the passive forms of minute organisms was one of the most potent factors by which belief in their spontaneous generation was kept alive.

Life is most evident, and hence best known in its active state. The passive state not infrequently escapes or eludes observation so that a much broader acquaintance with living things is necessary to appreciate it and understand its significance.

Passivity is observed among both plants and animals, though among the latter it is confined to comparatively few and usually to the lowest forms. It may be regarded as a state in which the living organism becomes capable of withstanding conditions incompatible with active existence. Thus, the cold of winter, the dryness of the desert, and the failure of the food supply are probable factors influencing the passage of living organisms from the active to the passive state, and the warmth of summer, the coming of rain, and the presence of food, factors in bringing them once more to a state of activity.

Reference.

Thomas H. Huxley: "Anatomy of Invertebrated Animals,' N. Y., 1885.

CHAPTER IV.

THE MANIFESTATIONS OF LIFE.

IRRITABILITY.

Irritability is that property of living substance by virtue of which it responds to stimulation. It is a universal and fundamental characteristic, and forms the starting-point of all vital manifestation. The behavior of living substance is determined by the stimulations it receives, and without stimulation it does nothing and cannot be recognized as living. When matter is no longer irritable, and when it fails to respond to stimulation, we declare it to be dead, or no longer living.

The stimuli that excite the irritable reactions, and thus govern and determine the vital manifestations are of two kinds: 1. Intrinsic, inherited, and regulating, and 2. extrinsic and modifying.

Stimuli of the first class determine that the living thing, regardless of its simplicity or complexity, shall conform to a certain type, perform certain functions pass through a definite cycle of existence, and impart a certain amount of its substance to new individuals of its own kind by whom it may be survived. Those of the second class initiate, accelerate, retard, or modify these effects.

Every living thing is thus the creature of circumstance, dominated and controlled by inheritance and environment.

The action of stimuli may be continuous, intermittent, or occasional, as to time; normal, deficient, or excessive as to intensity, and beneficial or injurious according to duration, intensity, and quality.

Irritability was first recognized and is most easily demonstrated and best known in its most exaggerated forms, where the response to the stimulation appears to be disproportionate to its intensity.

This has led to the erroneous impression that mani-

Fig. 3.—Venus' Fly-trap (*Dionæa muscipula*). An insectivorous plant. The traps for catching the insects are at the tips of the leaves and consist of two valves with spinous edges. At the centre of each valve are several small spines which act as triggers. When an insect disturbs several of these the trap springs and it is caught and compressed between the valves. An enzymic secretion is soon poured out by glands in the valves and the insect is slowly dissolved, its juices being utilized by the plant in its nutrition. (*Kerner and Oliver.*)

festations of irritability imply an expenditure of energy disproportionate to the force of the irritating agent. The finger touching the trigger of a gun exerts a very slight pressure, the force of which has no relation to the amazing explosive force that follows it; a small effort turns the throttle of a locomotive by which a heavy train may be set in motion.

These examples of results disproportionate to their respective causes have found their way into many text-books and unfortunately confuse the student, for they apply with accuracy only to conditions that may be compared to the charge in the gun or the vapor tension in the boiler. Thus, when we examine the conditions found among living things in which such disproportions are noted, and an explosive disturbance follows what seems to be a trifling stimulus, we find that instead of a simple reaction we have to deal with some complicated mechanism in which the transmission of the impulse from the cell stimulated to many other cells, results in an effect which is the sum of many separate stimulations.

This is the case with the Mimosa or sensitive plant whose leaves all close when a few pinules are touched, and with Dionœa, or the "Venus' fly-trap," in which, when a few hairs are touched, the leaf closes, entrapping the offending insect. The same condition is found in the higher animals whose nervous systems are so coordinated as to act reflexly, the prick of a pin or some other slight stimulation sufficing to set in motion a series of stimulations terminating in the involuntary and convulsive movement of a muscle, a group of muscles controlling a member, or even most of the muscles of the body.

That such explosive reactions are exceptional, and that many of the manifestations of irritability are appreciable only after the lapse of considerable time, and then only through slight changes, will soon become apparent.

Stimulations calling forth a normal expenditure of energy, the loss of which can be amply compensated for by the nutritive function, may continue indefinitely, as is evidenced by the continuous operation of all those stimuli that have to do with normal growth and function. Those calling for excessive expenditures of energy soon exhaust vitality, and throw the living substance into an inactive state known as *rigidity* or "*tetanus*." If, after the development of this state, time be given for the metabolic functions to restore the integrity of the proto-

plasm, irritability returns, but if further disturbance is effected, exhaustion and death may ensue.

Since all the reactions of irritability are associated with more or less marked expenditures of energy, they all result in metabolic disturbances, and are all associated with chemical changes.

Certain agents—cold, chloroform, ether, chloral, etc.—inhibit the irritative phenomena. These are called *depressants* and *anesthetics*, and are quite well known experimentally though they are not known to play any part in the normal vital processes.

Irritable Reactions Toward Stimuli of Unknown Nature.—Among these are included those stimuli by which the development of the organism is governed, and its automatic behavior determined. A superficial acquaintance with embryology is sufficient to show that under appropriate conditions the germinal cells of plants and animals invariably develop according to a fixed plan. Furthermore, the developed animal behaves according to a fixed plan of conduct inherited from its ancestors. In ignorance of the character of the impulses thus engaged, we look upon them as of physico-chemical nature.

Irritable Reactions Occasioned by Stimuli of Known Nature.—These external stimuli embrace all those agents by which the behavior of the organism in its relations to the external world is determined. The irritable responses to these agents are frequently referred to as *tropisms*, and receive special denominations according to their respective qualities.

Thermotropism or Response to Thermal Stimulation.

No living substance is indifferent to variations of temperature. It is temperature that makes the conditions under which life is possible, and it is temperature that stimulates activity when the proper conditions obtain. Thus, active life is impossible without water by

which the protoplasmic basis of the cells is kept moist and soft, protoplasmic currents established, and the molecular interchanges constituting metabolism made possible. If low temperature transform the water to ice, or if high temperature drive it off in the form of vapor, life must either cease or become inactive until the essential conditions are restored.

Freezing results in disintegration of the protoplasm; high temperatures, in coagulation of the delicate substance. Active vital manifestations are thus only possible within limits marking the vital endurance of the organisms observed.

A striking difference in temperature relations characterizes the active and passive states of living matter. Thus many plants are killed by frost, whose seeds are not injured by any known degree of cold; bacteria that are killed at 60° C., may, in the spore stage, resist exposure to 120° C. for a few minutes. This assumption of the latent or passive form subserves the useful purpose of enabling the animal to escape the rigors of winter, the excessive dry heat of the desert, and other temporarily unfavorable conditions.

Different kinds of organisms show striking differences in regard to temperature endurance. In general terms this bears a direct relation to the developmental complexity of the organism. The lowest forms of life sometimes show a temperature endurance ranging over 350° C.; the highest forms may not survive an actual change of body temperature amounting to more than 5° C.

Thus, the spores of certain bacilli may be exposed for an hour to the temperature of liquid hydrogen (−225° C.) and yet survive. When the temperature is slowly elevated, and the spores are watched, it is found that no change occurs until 6° C. is reached when an occasional spore germinates and a bacillus emerges. As the temperature ascends, such of these bacilli as have survived are found to be dividing, at first only at long intervals, then with increasing frequency until when 12.5° C. is reached,

division occurs every four or five hours; at 25° C. every fifteen or twenty minutes. Between this temperature and 40° C. there is no essential change, but beyond it multiplication ceases or growth becomes modified so that in certain species spores are formed as the bacilli cease to develop, in others spore formation ceases. When the temperature ascends beyond 60° C., no more spore-free organisms can be found alive. The spores, however, may endure ascending temperatures including exposure to 100° C. for an hour, and 120° C. for a few minutes.

This variation shows that there are several temperatures deserving special mention; the lowest at which the activity of the organism becomes manifested, known as the *minimum*, that at which the vital manifestations progress with greatest rapidity, the *optimum*, and the highest at which they can be continued, the *maximum*.

The temperature endurance of organisms differs in many cases because of special adaptations. In the case of the bacteria it is ability to enter upon a latent or spore stage; in certain lowly animal forms, it is ability to enter upon an encysted stage in which the delicate protoplasm becomes protected by a dense capsule; in higher plants protection against moderate cold is secured, in some species, through the development of a hairy covering by which the cold atmosphere is kept away, in others where no such provision is made and the plant is killed by the frosts, it prepared for the future generations either by the formation of seeds, some of which can endure any known degree of cold, or by a latent existence in the form of rhizomes or bulbs.

In the so-called "cold-blooded" animals, whose temperatures differ little from those of the surrounding atmosphere, cold retards the metabolic functions, and heat accelerates them. If such animals can be kept from actual freezing, they endure cold without much harm, and heat only injures them when the accelerated metabolism becomes a source of excessive waste to the cells.

The higher, "warm-blooded," animals and birds

maintain a stable body temperature through heat-regulating mechanisms, by which the heat resulting from the metabolic processes is prevented from radiating when the external temperature is low, or radiated rapidly when it is high. For these organisms any considerable variation in the temperature of the body itself is quickly fatal; so that, when they are unable to prevent loss of heat by radiation, through lack of proper protection in the way of hair or feathers, they quickly die of cold; or, if through any means they are prevented from radiating heat, they quickly die with an elevated body temperature resulting from the accumulation of heat.

The eggs of birds which have no means of maintaining or radiating heat, are affected by slight variations of temperature, and afford striking examples of the stimulating as well as the destructive effects of temperature. Thus, if a hen's egg be placed in an incubator under favorable conditions, the irritability of the germinal cell is shown at about 39° C. by division and a succession of changes that will eventually result in the development of a chick. If, however, the incubator cool, or if its temperature rise a few degrees and remain so for a few hours, development ceases and the embryo dies.

When we come to consider man we find a high degree of temperature susceptibility. Normally, the body temperature is 37° C. and at this point it is maintained by complicated heat-regulating nervous mechanisms, in spite of external conditions. His cells are, however, so susceptible to changes of temperature in the body itself that a variation of more than one degree cannot take place without subjective symptoms; a variation of more than two and one-half degrees, without subjective and objective symptoms and incapacitation from the usual activities of life; a variation of three degrees without prostration, or of five degrees without danger to life.

It is the thermal irritability of protoplasm that leads to the varying vital manifestations accompanying the procession of the seasons as it is seen in the temperate

zone, and the general variation of fauna and flora as we see it affected by latitude and altitude.

In the eternal winter at the earth's poles, and in the eternal snows of high mountain altitudes there is no life; on the lowlands near the earth's equator, where it is perpetual summer, life, both vegetable and animal, is most abundant and most active.

The most striking and most beautiful example of thermotropic irritability is to be seen, however, in the alternating summer and winter of the temperate zones.

During the winter months when the waters are locked in ice and the ground covered with snow, the landscape presents an appearance of desolation suggesting universal death. The plants seem dead, the trees are lifeless skeletons, the insects and smaller animals have disappeared, the birds have flown and only the evergreen trees, and most hardy birds and mammals remain. If the winter be exceptionally severe, many of these may be killed. As the position of the earth changes and the days lengthen and the warmth of the sun's rays strengthens, the conditions change. The snows and ice melt, and in the warm moist earth the roots and seeds swell and the tender grass and plants emerge. The trees soon spread their leafy canopies, the flowers bloom, the insects leave their hiding places, the birds return, the animals creep from their shelters, and the latent invisible life once more returns to its state of activity and vigor. But see how rapid is the accelerating influence of the increasing temperature in all these changes. Upon a frosty spring morning in the country, one notes the greening grass and the flower buds nestling in the sheltered places; an occasional insect clings feebly to the stem of a plant or crawl upon the ground, easily picked up, benumbed and stiff; perhaps a snake has curled upon a stone or stump to catch the morning sun, so stiff and sluggish as to fail to get away in time to avoid capture. Yet, by afternoon, the magic of the sun's warmth has effected a striking change: the grass is

greener, the flower buds have opened, the buds upon the trees have doubled their size or perhaps burst into tufts of tender leaves, the great bumble-bees of spring fly to and fro in a business-like manner, the toad is piping in the nearby pond, and the snake glides noiselessly but quickly out of the way as the vibrating earth tells of your approach.

In these examples the thermic irritability is manifested by changes so gradual that it is only through observation of their aggregate results that they can be detected, but examples are not wanting to show that upon those plants and animals so constructed as to enable us to observe them temperature exerts an immediate response. This is the case, however, only when the variations are considerable and the changes sudden. For example, if a Mimosa be cautiously approached by either a hot or cold object, the greatest care being exercised to avoid mechanical contact with the plant, the sudden change of temperature is sufficient to excite the irritable cells and provoke closure of the leaves. It is not improbable that the irritability of living matter is susceptible to the stimulating effect of any sudden change.

The subject must not be dismissed without questioning whether cold, as well as warmth, may not have a stimulating effect. Cold has a marked inhibitive action upon the vital processes and when sufficiently intense may terminate them; but that it acts as a stimulus as well is not impossible, for certain bulbs are found to grow more rapidly, and their plants to bloom more quickly if they are exposed for a short time, before planting, to an unusually low temperature.

The diminishing temperature of approaching winter may be responsible for the plentiful growth of hair and feathers in many animals and birds.

The application of cold to the human skin is followed by vasomotor stimulation resulting in contraction of the peripheral blood vessels, and the effect of a cold

wind upon the conjunctiva is accompanied by lachrymation or rapid secretion of tears in most human beings.

Thigmotropism or Response to Mechanical Stimulation.

External agents of indifferent chemical and electrical quality, and free from temperature variations to which their effects can be referred, excite varying reactions in living organisms according to the simplicity or complexity, activity or passivity of the organism stimulated.

Animal and vegetable organisms differ in their manifestations, the general freedom of motion among the animals as contrasted with the restricted movements of vegetables serving to explain the indifference of most vegetable forms of life to the effects of mechanical stimulation.

Fig. 4.—Leaves of Sundew. *a*. Tentacles closed over captured prey; *b*, only half of the tentacles closed. Somewhat magnified. (*After Darwin.*)

Examples of thigmotropism among plants are, however, not wanting. Thus, Mimosa resents a very slight mechanical irritation by closing its leaves, and Dionæa closes its leaves to entrap its insect victim as soon as more than one of the little hairs upon the surface have been disturbed. An insect alighting upon a leaf of Drosera excites the neighboring tentacles to curve upon and capture it. The tendrils of climbing plants are highly susceptible to the mechanical stimulation of bodies with which they come into contact. "Pfeffer found that they were not induced to coil by every touch, but only through contact with the uneven surface of solid bodies. Raindrops, consequently, never act as a contact stimulus; and even the shock of a continual fall

of mercury produces no effect, though contact with a fibre of cotton-wool weighing only 0.00025 mgr. is sufficient to stimulate the tendril to coil.

The effect of mechanical stimulation of certain parts of flowers by visiting insects is often shown in movements of the stamens, or pistil, by which direct and cross fertilization of the flowers is facilitated. Thus the stamens of the barberry flowers are irritable and when touched upon the inner surface curve toward the pistil.

FIG. 5.—Mimosa. A. Position of a leaf at rest. B. Position of contraction resulting from irritation.

Among animals thigmotropism or reaction to mechanical stimulation is almost universal.

The amœba falling upon the bottom of the pool in which it lives or touching the surface of a glass slide upon which it is observed through a microscope, reacts by extending pseudopods and slowly moves from place to place by the streaming of its body substance. As the pseudopods impinge upon mechanical obstacles they are withdrawn in favor of others whose progress is not obstructed. If the active amœba be touched with a needle, it immediately withdraws all of the pseudopods,

remains inactive for a short time, then again resumes its movement.

When Vorticella is touched, a sudden and powerful contraction of the pedicle results, drawing the little animal away from the offending agent. A whole colony of Carchesium may contract when one organism is irritated.

The rotifer with its "wheels" in motion, quickly withdraws the cilia if touched, is quiescent for a mo-

FIG. 6.—Vorticella nebulifera (Entire colony magnified). *C.V*, Contractile vacuole. A free-swimming individual with two rings of cilia is seen on the right. When irritated the pedicle undergoes a spiral shortening and the organism is quickly drawn away from the irritant. (*Masterman.*)

ment, then again expands them and continues to feed. Touched again, the same effect may be produced, or the animal may let go its hold and swim away to try a new place where it may feed undisturbed.

The fresh-water hydra behaves in a most interesting manner according to the stimulations it receives, and we soon perceive that the effects differ according to the quality of the stimulus. Thus, when one of the tentacles is touched by some minute swimming animal or plant,

movements of prehension, associated with discharge of the nettle threads may be provoked so that the object may be paralyzed, caught, and forced into the mouth of the animal. If, however, the disturbance be greater, the tentacles may be withdrawn and the animal retracted to a rounded mass scarcely recognizable as a hydra. If frequently disturbed, the animal may let go and move off to a position of greater security.

As these primitive reactions are observed, we may interpret their purposes to be primarily defensive as the animals at rest are less conspicuous and may escape the observation of their enemies. Soon, however, we come to realize that even in the pseudopod of the amœba we see the foreshadowing of a discriminating power, based upon the intensity and quality of the impression received, which becomes developed more and more perfectly until the tactile sense of the higher animals develops.

So soon as animals evolve a complex nervous system the importance of thigmotropic irritability increases, special organs being developed to receive and transmit it as the sense of *touch*, and with it probably comes the subjective appreciation of pain as well as the peculiar coordination of nervous and muscular stimuli known as *reflex action* by which involuntary escape from injurious stimulations is effected.

Chemotropism or Response to Chemical Stimulation.

Substances capable of exciting a deleterious action upon living substance are known as *poisons*.

Certain of them act by virtue of their ability to effect an immediate destructive combination with protoplasm and are known as *caustics* and may be subdivided into *coagulating caustics* by which the protoplasm is coagulated, and *liquefying caustics* by which it is liquefied.

Among the former may be mentioned the metallic salts, acids, and some of the essential oils; among the latter, bases such as potash, soda, ammonia, and arsenious acid.

Other poisons known to the chemists as *toxins* have an exciting or depressing effect upon the living substance by which life is eventually set aside without visible chemical alteration.

The effects produced by poisons bear a direct relation to their concentration; for many substances which effect rapid destructive influences in strong solutions are not only rendered harmless, but also useful by sufficient dilution, and many substances that are commonly utilized by the cells become injurious when presented to them in excess.

In dilutions so great that, recognizable, harmful effects are no longer to be expected, chemical agents may excite no irritable manifestations, or may provoke interesting and important reactions that are described as *positive* or *negative* chemotropism.

The chemical nature of many of the substances by which these reactions are excited is unknown, and in some of the experiments by which chemotropic effects resembling those seen in nature are developed, we cannot be sure that the natural and experimental conditions are identical because identical effects are observed.

That chemotropic influences play an important function in determining many of the vital manifestations is beyond question, though it is not always possible to pursue the investigation because information concerning the nature of the chemical stimuli is so defective.

Pfeffer found that when motile spermatozoids of ferns are suspended in water they are influenced by malic acid. Thus if a capillary tube containing a dilution of this agent be introduced into the water containing them, the cells swim toward it and quickly enter in response to positive chemotropic influences. From such an experiment it seems justifiable to conclude that the spermatic elements of ferns as well as of other cryptogams find the appropriate female elements to be fertilized by virtue of chemotropic influences. Among the higher plants, in which pollination is effected by currents of air which

carry the pollen from the anthers to the stigma, or by insects and birds that carry the pollen grains from flower to flower, chemotropism is shown by the inability of the pollen grains of heterologous species and the ability of those of homologous species to grow into the stigma and descend to the ovules below.

The general explanation of the ease with which specific integrity is maintained, and hybridization made difficult in both plants and animals, probably rests upon conditions of positive and negative chemotropism existing between the male and female sexual elements of similar and dissimilar species.

Among animals whose ova and spermatozoa are liberated freely in the water in which they live, the union of the cells must be determined by chemotropic influences. Among higher animals in which the spermatic fluid is emitted into the sexual organs of the female, it must be chemotropic influences that govern the movements of the spermatozoa during their progress toward the ovum, and finally determine their entrance into it instead of into other cells with which they may come into contact during the interval.

Chemotropism is specialized in the higher animals as taste and smell.

A. *Sitotropism or Reactions toward the Stimulating Influences of Food.*

This can be differentiated with difficulty from simpler forms of chemotropism. The wear and tear of the cytoplasm of the cells of living organisms brought about through their activities, makes it imperative that means be provided for reintegration of the impoverished tissues. A food supply, therefore, becomes imperative.

The simple character and almost universal distribution of the foods of plants make it unnecessary for them to manifest sitotropic activities. The more complex food requirements of animal organisms determine that the majority pursue or catch their food.

Sitotropic reactions, however, are observed among lowly motile plants, such as bacteria. Thus Hertwig has found that a 1 per cent. solution of beef-extract or of asparagin has a pronounced attractive effect upon Bacterium termo, Spirillum undula and numerous other organisms. If a fine capillary tube filled with such a solution be held in contact with a drop of water containing such organisms, a considerable mass of them will be found plugging the mouth of the tube in from two to five minutes, showing their movement from the poorer to the richer nutrient supply in response to sitotropic influences.

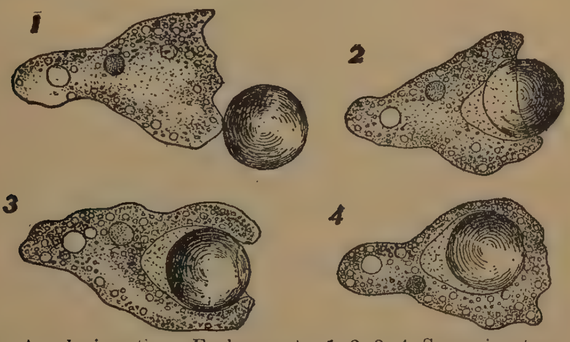

FIG. 7.—Amœba ingesting a Euglena cyst. 1, 2, 3, 4, Successive stages in the process. (*Jennings.*)

The amœba gliding about takes up one after another objects suitable for food, as they come within its reach. If few such be found, its movements become more active and its excursions longer.

A hydra with tentacles spread awaits the arrival of its prey. If none come, it changes its position and tries again.

Caterpillars hatched upon the trunk of a tree climb to the branches and reach the leaves upon which they feed.

As we ascend the scale of life, and the behavior of the organism becomes more and more complicated, the sitotropic, hydrotropic, and oxytropic reactions become so

confused with what are called instincts, at the foundation of which they undoubtedly lie, that they are apt to be lost sight of.

The struggles of a starving man to secure food by honest employment, by change of locality, by solicitation or by theft, though rarely so regarded, are as certainly determined by positive sitotropic—internal chemical—conditions and by the necessity for the reintegration experienced by his cells and expressed as hunger, as is the more simple behavior of the hydra or the amœba.

B. *Hydrotropism, or response to the stimulating influence of water,* is an important form of chemotropic reaction the effects of which are observable among nearly all forms of life. Care must be taken, however, to separate such activity or quiescence as may depend upon the presence or absence of water with favorable and unfavorable conditions depending thereupon, from the real hydrotropic reactions in which the active organism behaves peculiarly in its efforts to effect the best utilization of available water.

As usual the reactions consist of positive and negative movements.

The myxomycetes show distinct positive hydrotropic reactions. Thus, if one be placed upon a piece of blotting paper so arranged as to be dry at one end and damp at the other, the amœboid movements of the plant slowly bring it to the moist end of the paper. If, now, the paper have its position reversed, so that what was formerly the dry end becomes the moist end and *vice versa,* the organism gradually spreads its amœboid network more and more toward the moisture until, in the course of time, it has again traversed the length of the paper. This is positive hydrotropism and represents the common form.

Seedling plants usually arrange themselves in such manner that the stems grow upward toward the light and heat, while the roots grow downward into the soil

in search of moisture. If, however, they are artificially so arranged that the source of moisture is above, the rootlets turn up instead of down in order to obtain it.

The hyphomycetes or moulds which require much moisture for successful growth, when cultivated in a bottle containing a few drops of liquid, are found to conform in distribution to the moisture of condensation upon the sides of the glass.

The hydrotropic behavior bears some relation to the

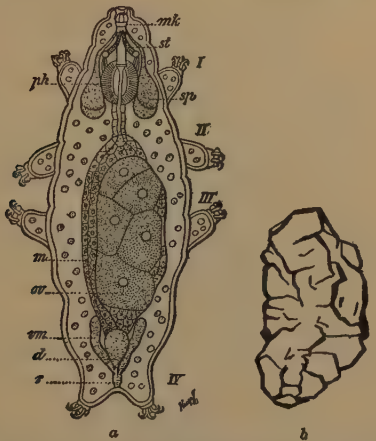

FIG. 8.—"Bärentierchen." This animalcule is capable of resisting the ill effects of loss of water. *a.* The active animal. *b.* The same in the dry state and apparently dead. When moistened, it absorbs water and resumes its active form again. (*After R. Hertwig.*)

developmental stage of the organism; thus in the myxomycetes the positive hydrotropic reactions continue only during the vegetative stage and so soon as the fructification begins, and it is desirable to keep the sporangiophores dry, negative hydropism begins and the reactions are reversed.

Loss of moisture and consequent inability to maintain activity leads to a variety of manifestations among both animals and plants. Among the most lowly

it usually results in the formation of spores, or the entrance of the organism upon an encysted or latent stage. Among the higher plants inability to assume such forms and to transport themselves to a new neighborhood result in death; in the higher animals it results in various movements for the purpose of obtaining the essential moisture. Thus land crabs are compelled to travel every day or two to the water for the purpose of moistening the branchiæ, and among still higher animals the drying of the pools and springs leads certain of the fishes and amphibia to bury themselves deeply in the mud, where they remain inactive until the return of rain. Still higher animals such as the mammalia may be compelled to make long periodical migrations corresponding to the periods of rainfall and drought. Failure of the water supply is followed by death in such cases.

C. *Oxytropism, or Response to the Stimulating Effects of Oxygen.*

This form of chemotropism results from the necessity which all living things experience with reference to oxygen, which is essential to all forms of life. For most living things the free oxygen of the atmosphere is sufficient, but a few forms of life are unable to make use of it and are obliged to secure such oxygen as they need by the analysis of compounds containing it. This is best exemplified by the anaërobic bacteria, which, appearing to be overstimulated by the uncombined element, show no signs of activity until it is completely excluded, when they begin to analyze the compounds from which they may obtain it. The greater the available oxygen in these compounds, the better and more actively the organisms multiply, so that solutions of carbohydrates form the best substratum for their cultivation.

When, on the other hand, aërobic bacteria occur under conditions which make it difficult to secure sufficient uncombined oxygen for their purposes, interesting phenom-

ena are sometimes observed; as, for example, intimate association with diatomes in order that they may profit by the oxygen thrown off by the little plants. Verworn observed a group of bacteria (Spirochæte plicatilis) surrounding a Pinnularia in great numbers, though elsewhere in the preparation they were absent. The bacteria were all at rest and were present in greatest

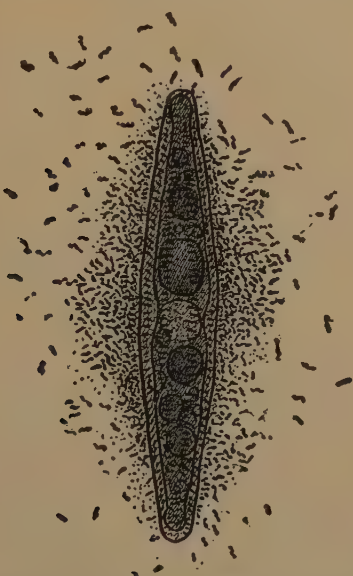

FIG. 9.—Mutualism of diatome and bacteria. The bacteria by which the diatome is surrounded are profiting by the oxygen it gives off in its metabolism.

numbers near the centre of the organism. Suddenly the diatome moved off a short distance, when the bacteria left behind and remaining quiet a short time, swam after it, surrounding it again in a similar cluster. It was no doubt the oxygen given off by the plant that attracted the bacteria. In microscopic specimens, prepared by covering a drop of water with a cover-glass, Hertwig points out that necessity for oxygen eventually deter-

mines all the bacteria, flagellates, and ciliates to the edges of the glass or to the air bubbles caught in the liquid.

Hertwig also points out that if a plasmodium of Aethalium septicum be enclosed in a cylindrical vessel containing boiled water, the vessel closed with a perforated cork and inverted over a dish of fresh water, the plasmodium soon escapes from the boiled water to the aerated water through the opening in the cork.

If fishes be kept in an aquarium without plants or other means of aerating the water, they will be found to behave in a peculiar manner as the oxygen becomes exhausted. They first rise to the surface near which they remain. As the available oxygen diminishes, they swim along the surface with the mouth open until a globule of air is secured and forced to the back part of the mouth in order that it may be brought into contact with the gills. By this means asphyxia may be postponed for some time.

When the higher animals are excluded from oxygen a complicated series of nervous and muscular manifestations, collectively known as *asphyxia*, occurs. They are chiefly characterized by involuntary muscular efforts, brought about through excitation of the automatic respiratory centres, the purpose of which is to relieve the organism of the accumulated CO_2 and to secure fresh O. As the condition progresses the innervation being more and more profoundly disturbed, the movements become more and more violent until the animal falls convulsed and exhausted.

Heliotropism or Response to Photic Stimulation.

With but few exceptions living organisms are sensitive to light and react according to conditions not all of which are understood.

It is found by experiment that the different rays of the solar spectrum have varying effects upon living organ-

isms; some, like the red and yellow rays, being useful; others, like the blue and violet rays, being prejudicial in action.

Many living organisms flourish under the direct rays of a tropical sun, others are quickly killed by direct sunlight, still others seem to find the most favorable conditions in the perpetual darkness of caverns or the depths

Fig. 10.—A seedling of the White Mustard in a water culture which has first been illuminated from all sides and then from one side only. The stem is turned toward the light, the root away from it, while the leaf-blades are expanded at right angles to the incident light. *K,K,* Sheet of cork to which the seedling is attached. (*Strasburger, Noll, Schenck, and Karsten.*)

of the sea. It is thus possible to describe positive and negative heliotropism among both plants and animals.

Certain bacteria are highly susceptible to light, and some species are quickly killed when exposed to the direct rays of the sun. Bacteria and indeed most fungi seem to flourish best in diffused light; a few appear to grow best in the dark, and sometimes certain functions

of bacteria, such as the formation of pigment, take place only in the dark, as in Bacillus mycoides roseus.

To the higher plants, light is indispensable and their heliotropic reactions are correspondingly interesting.

A familiar example of positive heliotropism in the higher plants is found in the sprouting of potatoes in the cellar. If the cellar be very dark, the sprouts are long,

FIG. 11.—Mimosa pudica. A. Entire plant in the daytime with leaves expanded. B. The same in the position of contraction assumed at night. (*Verworn.*)

slender and without color. If there be a distant window from which a dim light is admitted, the shoots on the window side are larger and more vigorous. If the light admitted by the window reach a certain intensity, small leaves appear at the ends of the sprouts, and show pale green color. This growth of the potato is entirely different from that seen when the tuber is planted in the

earth out of doors, when a sturdy stalk with abundant dark green leaves assumes a vertical growth.

Whoever has beautified his window with growing plants must have observed how regularly the leaves turn toward the light, and how necessary it is to turn the pot around day after day if symmetrical development of the plant is desired. The movement of the leaves depends upon positive heliotropic movements of the stems and petioles by which the leaves are kept at right angles to the incident light, thus exposing the entire upper surface, and enabling its superficial cells to benefit by its influence. The study of the entire plant usually shows that the root turns away from the source of light as the leaves turn toward it. The leaves are therefore positively, the roots negatively, heliotropic.

Certain plants such as Mimosa partially or completely close the leaves when the sunlight wanes, to open them again when it waxes. Many flowers close during the night to open again when the morning sun strikes them. The morning-glory and dandelion are familiar examples.

It is, of course, difficult to exclude the heat accompanying the sun's rays as a factor in these movements, yet the amount of heat in the feeble light of the cellars in which potatoes sprout can scarcely be accompanied by sufficient heat to explain the behavior already pointed out, and the disastrous effects of absence of light in the presence of heat would indicate that it is the light and not the heat that effects the reaction. Thus, if a well-grown, healthy plant be transferred to a warm but dark room, in spite of the careful maintenance of all other healthy conditions, the plant soon sickens and the leaves and flowers fall off.

The positive heliotropic reactions subserve a useful purpose in bringing the essential organs of the plant into the sunlight without which its important functions are impossible. Thus, in the dark no chlorophyl can be formed, and without chlorophyl the proper nutrition, growth, and perfection of the higher plants cannot be carried on.

The roots of plants, whether terrestrial or aerial, contain no chlorophyl and, like the fungi, are negatively heliotropic. A majority of the flowers that open in the sunshine are more or less colored. The negatively heliotropic flowers that open only at night are invariably white.

Heliotropism among animals is evidenced by a general activity during the daytime as compared with quiescence at night. Like the flowers, the animals that enjoy the sunshine are apt to be variously colored; those that live in the dark are apt to be white.

The varying intensity of the sun's rays provoke interesting temporary changes in the skins of many animals

FIG. 12.—Positive heliotropism of *Spirographis spallanzani*. The source of light being on the left, the polypi all turn in that direction. (Loeb.)

through their stimulating effects. Thus the skin of the squid contains a great number of small chambers in which an inky fluid is contained. These chambers communicate with one another; and when the animal is upon a dark object the superficial chambers dilate to receive added fluid, making the skin dark; when it is upon a pale surface, they contract, driving the fluid into the deeper chambers and making the skin pale.

The chameleon is well known because of its ready change of color as it moves from object to object. Here the mechanism is different and the color change depends upon certain migratory pigmented cells of the skin which change their positions with surprising rapidity according

to the intensity of the light reflected upon the animal by surrounding objects. The same change of color is seen among many other reptiles and some batrachia.

The attractive influence of a lamp upon nocturnal insects is a striking example of positive heliotropism, many of the insects actually flying into the light to meet destruction.

But in the animal world the most striking example of the irritability of the cells toward light is shown in that particular and adapted form known as the sense of vision, where the light rays are caught and intensified so as to act upon a special organ, the retina. Animals living in perpetual darkness are either devoid of visual organs or possess their rudiments only.

The cells of the higher plants contain peculiar granules known as *chloroplasts* whose office is the production of the chlorophyl and other colored substances peculiar to the leaves and flowers. When these are present in the deeper cells of the plants, into which light cannot penetrate, or when the plants are kept in darkness, they develop into *leucoplasts*, but if at any time light reaches them, a change is effected through its stimulation, and they become changed into the *chromoplasts* which give the fruits and flowers their varied colors.

The effect of light in the transformation of these chromoplasts can be studied by placing a photographic film upon the surface of a growing fruit—a large apple answers the purpose well—exposed to the sunlight. The admission or exclusion of the sun's rays, by the denser or lighter portions of the negative, results in a photographic picture upon the fruit caused by the formation of perfect chromoplasts where the light penetrated and imperfect formation where it was withheld. Interesting and beautiful pictures may thus be produced.

The effects of the sun's rays upon the human skin are well known, though it is difficult to differentiate between those attributable to heat and those due to the light alone. Exposure to the direct rays of intense sunlight

result in injurious effects, known as sunburn, characterized by redness (hyperæmia) and the formation of blisters (vesication) and followed by loss of the superficial layers of the epiderm and increased pigmentation of the deeper layers, usually appearing as a uniform bronzing of the skin, though in certain individuals, mostly in those of fair complexions, the pigment may collect in small dark spots (freckles).

Continued exposure to the sun leads to deep bronzing and may explain why the races of men inhabiting those portions of the earth where the rays of the sun are most intense are uniformly darker in complexion than those of less sunny climes.

Concentration of the sun's rays by lenses results in intensification of both heat and light rays, the former being intensely destructive to life. If, however, the concentrated rays are passed through cooling apparatus so as to be deprived of the heat, it is found that the light rays are also destructive to cell life. Finsen has devised a method of destroying certain tumors (squamous cell carcinoma) by exposing them to such concentrated light rays, the abnormal cells of the tumor seeming to be less able to endure their effects than those of the normal tissue cells among which they grow.

Galvanotropism or Response to Electrical Stimuli.

Electrical currents of high intensity are destructive to all forms of life through chemical and physical alterations effected in the protoplasm. Currents too mild to be destructive influence living matter but slightly, and little evidence is at hand to show that stimuli of electrical nature play any important rôle in the vital processes.

Plants seem to be far less sensitive than animals to the effects of electric currents. The phanerogames, indeed, show no visible electrotropic reactions, though the cells when examined microscopically, as in the hairs of

Tradescantia, show a disturbance by which the delicate protoplasm is collected into nodular masses.

When amœba and leucocytes are subjected to the irritation of galvanic currents passed through the fluid in which they are suspended, they draw in their pseudopods, cease amœboid movement, and may even suspend the cytoplasmic circulation. If the current be of mild intensity, its effect soon wears off and activities begin

Fig. 13.—Result of electric stimulation of plant protoplasm as shown in the cells of the hairs upon Tradescantia leaves. A, Quietly streaming cytoplasm; B, changes produced by the passage of an electric current, the cytoplasm being gathered into small globular masses at c and d. (*After Kühne.*)

again. If, however, its intensity be greater, disintegration of the protoplasm follows.

When water containing paramœcia is subjected to a constant current of mild intensity passed from one side to the other, the organisms abandon the positive (anode) pole and collect at the negative (kathode) pole.

When a single organism subjected to a galvanic current is examined microscopically it is found that

the effect of the current is to alter the position of the cilia at the kathodal end or side, so that the organism changes its direction and swims backwards.

If the experiment is performed with water containing both ciliates and flagellates, the electrotropic reaction is found to be different for the two kinds of organisms.

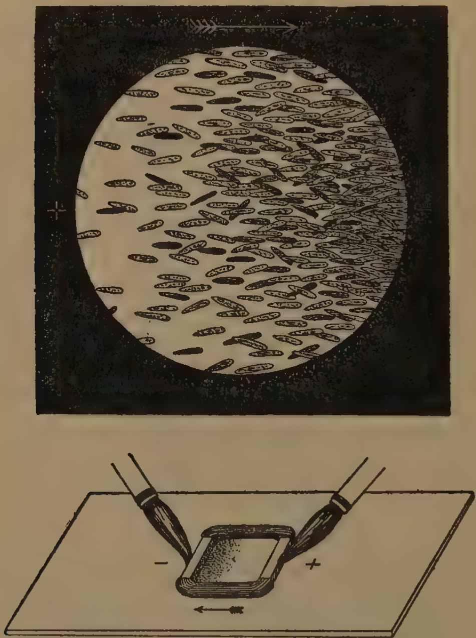

FIG. 14.—Electrotropic reaction of Paramœcium. The lower figure shows the mode of applying the electric current, the upper a microscopic field showing the migration of the organisms from the + to the − pole. (*Verworn.*)

The ciliates, as has been shown, tend toward the kathode, but the flagellates tend toward the anode.

The most active responses to electrical stimuli appear in animals possessed of a nervous system, by which the activity of other parts of the body is dominated. All nervous tissue seems to be highly susceptible to elec-

trical conduction and stimulation, so that the application of an electrode to the central end of a motor nerve is followed by immediate muscular contraction; to the central end of a secretory nerve by secretion on the part of the glands governed by the nerve, and to the peripheral end of a sensory nerve by painful sensations.

The facility with which electric currents are transmitted by the nerves has led to the assumption by many that electricity and nerve force are identical.

In the transmission of electric currents along the nerve fibres there is a difference in degree only between anodal and kathodal stimulation.

Loeb transmitted an electric current through a trough of water containing an Amblystoma and found that a secretion of sticky white mucus appeared upon the skin wherever it was struck by the current waves emanating from the anode.

Currents of considerable intensity produce cytolysis or disintegration of the protoplasm probably by transformation of the electrolites of the contained salts. Kühne found that when a rhizopod known as Actinosphærium was subjected for some time to a constant current, it began to disintegrate upon the anodal side.

Currents of high intensity passed through the higher animals cause death from destruction of the nervous system. It is in this way that men are killed by contact with "live" trolley wires and by electrocution.

Geotropism or Response toward the Force of Gravity.

The effect of gravity upon living things is pronounced and occasions a variety of reactions. It seems to be more clearly manifested among the vegetable than among the animal organisms because of the greater freedom of movement of the latter, but gravitation reactions, such as maintaining the equilibrium, are to be found among the very highest animals.

Among the lowest animals and plants, especially those that are free and motile, geotropic reactions are either undetermined or vague.

Among the fungi, however, with increasing complexity of structure, there is an increasing disposition toward a definite adjustment of the organism with reference to the earth's surface. Thus among the moulds, Aspergillus and Penicillium most commonly direct their sporangia upward, and among hyphmycetes in general the aerial hyphæ grow perpendicularly to the plane of the earth's surface.

Among the Basidiomycetes, the Polyphoreæ and Agaricineæ, which include the mushroom and toad-stool-like organisms, tend toward a perpendicular position, the pileus spreading in a plane corresponding to that of the earth's surface.

The general tendency of the higher cryptogams is to maintain a line of growth perpendicular to the plane of the earth's surface.

The same general tendency pervades pretty much the whole group of phanerogams.

In considering the geotropic reactions of plants, it becomes necessary to speak of positive, negative, and lateral geotropism and to make brief mention of diageotropism.

In such plants as show typical geotropic reactions, the stem which rises vertically, that is, perpendicularly to the plane of the earth's surface, is negatively geotropic; the branches that extend from it in a plane more or less parallel with the earth's surface, diageotropic, and the tap-root, that descends perpendicularly to the earth's surface, positively geotropic.

This behavior takes place regardless of the sources of light and heat and in obedience to the force of gravity alone.

Knight found that if germinating seeds were fastened to a rapidly revolving wheel moving in a vertical plane, by which the force of gravity was set aside, the direction

of growth obeyed the laws of centrifugal force and the shoot grew toward the centre of attraction and its root away from it. When the wheel was revolved in a horizontal plane, the force of gravity not being overcome, the plant being subjected simultaneously to both centrifugal force and that of gravitation, took an intermediate position, directing the shoot upward and toward the centre, the root downward and away from it.

It is a common observation that plants that have

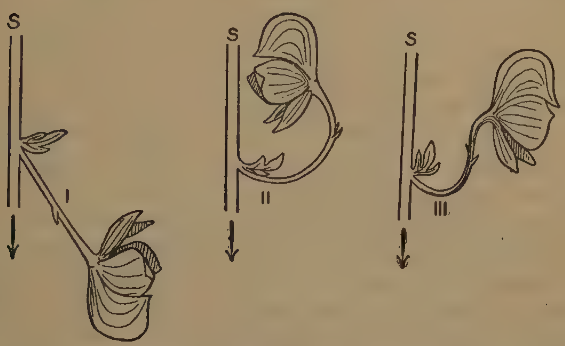

Fig. 15.—The movements by which a flower of *Aconitum napellus* regains its proper position when the axis bearing it (s) is inverted. I. Inverted position; II. position resulting from geotropism, the flower facing the parent axis; III. flower again facing outward, after the exotropic movement. (*Strasburger, Noll, Schenck and Karsten.*)

made a false start, through accidental circumstance or intentional interference, adjust themselves to the geotropic influences by certain curvatures that result from increased growth of one side and retarded growth of the opposite side, the region of greatest growth being, in general, that of greatest curvature. This applies both to the negatively geotropic stems and the positively geotropic roots. As soon as the unequal growth succeeds in establishing the upright position, it ceases and symmetrical growth progresses.

Lateral geotropism is best exemplified in climbing

plants whose stems twine about upright supports. The lateral unequal growth is supposed to depend upon geotropic stimulation of the cells in one lateral plane with resulting horizontal curvatures.

In all of these examples the geotropic influences are manifested through the combined effects of minute changes in many cells, the changes in the individual cells being too slight to be recognized.

Among animals, as has been pointed out, geotropic reactions are less easy to define. With few exceptions, however, all animals tend to maintain a definite position with reference to the earth's surface and axis, which, of course, is a form of geotropism. Plant-like animals are best adapted to the purpose of demonstration and an examination of the members of Cœlenterata, especially the Hydrozoa and Actinozoa, reveal a number of forms whose geotropic reactions are pronounced.

These animals are characterized by a cylindrical body with a stolon or foot at one end and a circle of tentacles at the other. In general they assume a position with the stolon down and the tentacles up. One of these hydroids, Tubularia mesembryantheum, was experimented upon by Allman who found that if the polyp was cut from the stem, a new polyp regenerated; if the stolon was cut from the other end a new stolon developed. If both were amputated, a new polyp was reproduced and a new stolon reproduced, but always at those ends from which they had respectively been removed.

Loeb endeavored to find out whether this was due to the animal being, as Allman expressed it, polarized, and discovered that when both extremities were amputated and the oral or polyp end embedded in sand, while the upward directed aboral or stolon end was surrounded on all sides by water, a polyp instead of a stolon invariably developed at the aboral end.

While not attributed to geotropic influences by Loeb, it would seem as if this peculiarity might have some reference to them.

Loeb points out that certain Holothurians tend to creep vertically upward when placed upon a plane surface. If the plane be slowly turned so that the position is inverted, the animal remains quiet until accommodated to the new order, and then again begins to creep upward. This is an example of negative geotropism.

Among the higher animals the disposition to assume definite positions with relation to gravitation is even more pronounced. The mechanism by which it is accomplished is complicated, being partly voluntary and partly reflex, and accomplished through visual and tactile impressions, as well as through the semicircular canals of the internal ear which are supposed to be equilibrating organs.

Inversion of the higher animals, or the forced assumption of any abnormal position, is followed by intense anxiety to resume the normal, but so many factors cooperate to produce the effects that it becomes extremely difficult to determine in how far they are geotropic in character.

CONDUCTIVITY.

By conductivity is meant the conduction or transmission of any stimulus from the part immediately irritated or stimulated to others more or less remote.

Conductivity is almost as widely distributed a property of living substance as is the irritability upon which it depends.

As irritability was difficult to determine in the absence of immediate response, so it is only possible to determine the extent of conduction in cases in which it leads to visible effects.

In the behavior of the plasmodia of the slime moulds we find evidences that the effect of stimulation is exerted upon the whole, not upon that particular portion stimulated. Thus, there must be transmission of the stimu-

FIG. 16.—Sundew (*Drosera rotundifolia*). Each leaf is covered with tentacles whose function is to catch the insects upon which the plant preys. Each tentacle is covered with a sticky secretion which detains the victim until neighboring tentacles are able to curve over it and completely invest it. The insect is then smothered, and digested by enzymic secretions, its substance aiding the nutrition of the plant. (From Bergen and Davis's "Principles of Botany," Ginn & Co., publishers.)

lation from the part stimulated to all parts of the organism.

Among such of the higher plants as show response to stimulation we find the effects to result from the sum of the reactions taking place in numbers of cells through irritable impulses transmitted from cell to cell from the point of primary stimulation. For example, when the hairs upon the expanded leaf of Dionœa are irritated, the leaf closes through changes effected in cells remote from the point of stimulation. Indeed, so many cells are affected and the effect of their united activity so pronounced as to lead to a result strikingly disproportionate to the intensity of the stimulation. The same general principle applies to Drosera and other insect-catching plants. A few tentacles being stimulated by the insect, many bend over and assist in catching it.

Another example in which still more widespread conduction of the impulse from cell to cell is found in Mimosa, for when a single pinnule of one of the leaves is actively stimulated, the whole leaf, or the whole branch, or, indeed, the whole plant, may be so disturbed as to close its leaves. Here we see indubitable evidence that the impulse to react passes from cell to cell along the pinnules, petioles, branches, and stems.

Among animals conductivity is more easily demonstrated because of the generally greater activity of animal organisms. In plants the signs of conductivity and irritability are most evident among the lowest forms, but in animals they are most obvious and best developed among the highest forms.

When a moving amœba is irritated in such manner that a single pseudopod is affected, all of the pseudopods are drawn in, the spherical shape is assumed, and the animal remains quiet for a time. When the delicate pseudopods of any of the radiolaria are touched, they may be withdrawn, or all of the pseudopods may be withdrawn as in amœba. In these illustrations it will be seen that a disturbance at one point is transmitted

throughout the entire cell, all parts of which are affected by the disturbance.

When vorticella is touched, the irritation is immediately transmitted to the pedicle, which contracts suddenly and violently, withdrawing the animal from the harmful influence. In Carchesium, disturbance of one individual may result in contraction of all the stalks so that the whole colony is withdrawn from the source of stimulation.

When a tentacle of one of the hydroids discovers some

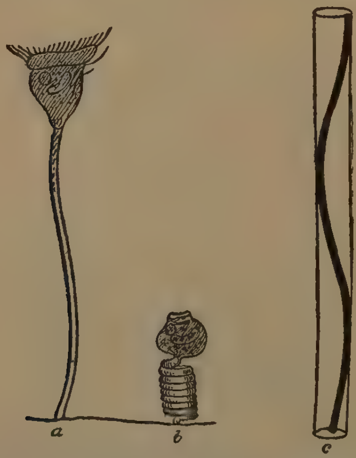

Fig. 17.—Vorticella. *a*, Extended; *b*, contracted; *c*, section of the stalk showing the elongate contractile (muscle) fibre in its interior. (*Verworn.*)

object useful for food, the stimulation is quickly imparted to other tentacles in order that it be firmly grasped and brought to the oral opening.

In the higher animals whose movements must be precise and well-coordinated, this simple transmission of irritable reaction from cell to cell is inadequate because too slow to meet the requirements, and is replaced by specialized cells, nerve fibres, greatly elongated in form, and able to establish immediate communication between

the various parts of the organism. Among these highly specialized conducting tissues we find terminal endings by which the impulses or stimuli are received, fibres by which they are transmitted, and ganglionic cells by which they are received and systematically redistributed, fibres by which the new impusles are further transmitted, and finally nervous terminations by which the final stimuli are imparted to the particular cell groups for which they are intended.

MOTION.

Motion and locomotion are widespread vital manifestations, and are among those for which we first seek in endeavoring to decide whether or not some newly discovered object is living or not lving. If it move through activities resident within itself, we are satisfied that it is alive, but if through obedience to external forces, further investigation of its properties and consideration of its other manifestations become necessary.

It is taught by some biologists that some movement is to be found in every living thing, but it has already been pointed out that life exists in both active or kinetic and latent or potential forms and that what applies to the former may not apply to the latter. While, therefore, it is quite true that some form of motion exists in all active life, it is difficult to imagine it in such latent forms of life as the spores of fungi and the dry seeds of plants.

Motion and locomotion must not be confused. Many living things are in constant motion, to which locomotion is impossible.

One must also avoid the hasty conclusion that no movement is in progress because none can be seen. In reality the motion that can be seen is greatly outweighed in importance by the motion that cannot be seen. Thus one sits quietly in a chair for a time, then rising, takes a turn about the room and reseats himself. To the uninformed, it may appear as if the only movements made

comprised the little walk about the room, yet all the time he sat quietly in the chair, there were going on within his body a great number of invisible movements, for the heart was continually beating, the blood and lymph were continually circulating, the function of digestion was probably in progress with its involved movements of secretion, muscular contraction, absorption, excretion, etc., and during all this time the cells of the entire body were more or less actively nourishing themselves, their cytoplasm continually flowing to and fro in rhythmical currents.

We are accustomed to think of plants as motionless things, yet to one who has come to the realization of what plant life really means a growing plant is full of energy. There are currents of sap ascending the stems and flowing into the leaves, bringing to these great cellular laboratories the nutritious substances absorbed by the rootlets from the soil. As the sap comes in it is absorbed by the active cells which work it over, extracting useful substances, manufacturing new compounds, and then sending these away in currents, sometimes to the flowers, sometimes to the seeds, and sometimes to the roots where the newly prepared compounds, changed or unchanged, are stored up for future needs. Add to this the continuous accession of new cells by multiplication of those already present, the necessary gaseous and nutritional changes by which the substance of the cells is itself kept alive, and we find the plant, seeming all the while to be inactive, full of life and motion.

Cytoplasmic Circulation.—This form of movement is in constant progress in every active cell. It is most active and most easily observed in young cells, especially vegetable cells, such as are found in the hairs of Tradescansia, which are very soft and moist, and in the amœba. It consists in a regular flowing motion of the cytoplasm within the confines of the cell and subserves the double purpose of affording all portions of the protoplasm an opportunity of coming into contact with

the contained nutritious matter, and of enabling the nutritious matter to be acted upon and transformed by the enzymic substances contained in the cytoplasm. It is probably indispensable to the phenomena of molecular exchange constituting metabolism, and may therefore be presumed to be in uninterrupted progress in every active living cell. The more active the cell, the greater the need of such circulatory movements and the more active they become.

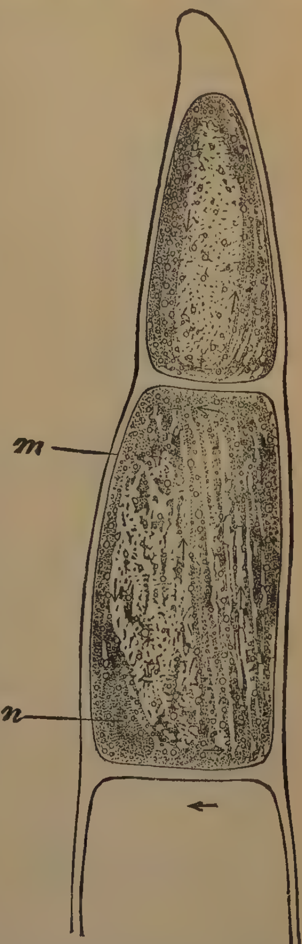

FIG. 18.—Two cells and a part of a third from the tip of a "leaf" of a stonewort, showing rotation of the protoplasm in the direction of the arrows. (*Sedgwick and Wilson.*)

In the higher protozoa the cytoplasmic circulation is facilitated by certain organs known as contractile vacuoles. Thus if one of the large vacuoles in a Paramœcium be carefully watched it will be found to undergo a rhythmical change of place, becoming rapidly smaller and disappearing where first seen, to appear and grow correspondingly larger at a new situation. After a given interval contraction again takes place and the vacuole reappears in the original situation as it disappears from its recent one. These vacuoles thus perform a function suggestive of a primitive heart, keeping the cytoplasm constantly agitated by currents of circulating fluid.

Amœboid Movement.—This is movement of a kind best exemplified by the Amœba, and is a primitive form of locomotion. It consists in a peculiar flowing of the cytoplasm, but instead of being confined to the bound-

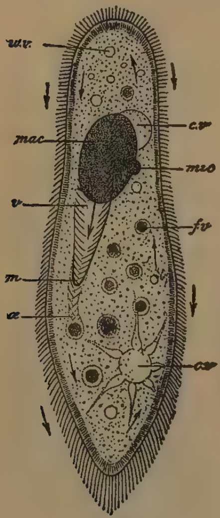

Fig. 19.

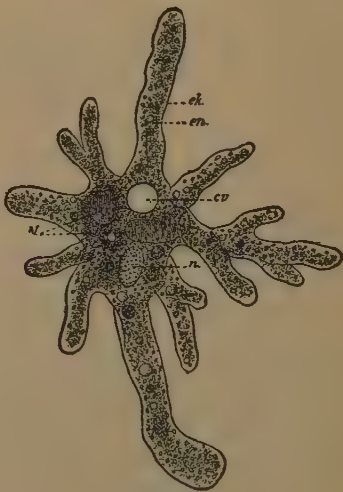

Fig. 20.

Fig. 19.—*Paramæcium caudatum*, from the ventral side, showing the vestibule *en face;* arrows inside the body indicate the direction of protoplasmic currents; those outside, the direction of water currents caused by the cilia. *c.v*, Contractile vacuoles; *f.v*, food vacuoles; *w.v*, water vacuoles; *m*, mouth; *mac*, macronucleus; *mic*, micronucleus; *æ*, œsophagus; *v*, vestibule. The anterior end is directed upward. (*Sedgwick and Wilson.*)

Fig. 20.—Amœba proteus: *n*, nucleus; *c.v*, contractile vacuole; *N*, nutrient material in process of digestion; *p*, pseudopod; *en*, endosarc; *ek*, ectosarc. (*From R. Hertwig.*)

aries of the cell, it results in an extension of these boundaries in the form of what are called pseudopodia.

Jennings has described the movement as comparable to rolling. The upper surface continually passing forward and rolling under at the anterior end so as to form the lower surface. This causes the moving amœba

to appear to have its substance continually flowing forward in the direction of progress.

As the moving amœba is watched it seems to be uncertain as to the best course to pursue so that the anterior edge is not uniformly extended, but commonly flows out into elongate rounded processes, the pseudopodia, one of which becomes larger and larger as the cytoplasm flows into it, while the remainder are gradually withdrawn.

Progress is effected with great slowness, and through an unending series of changes in the shape of the organism.

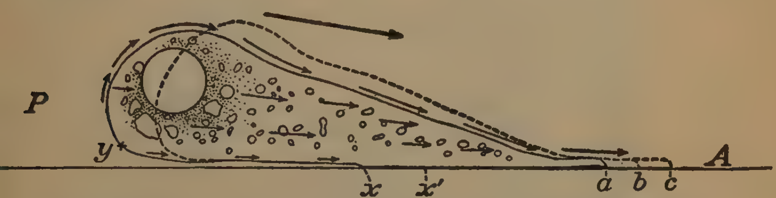

FIG. 21.—Diagram of the movements in a progressing amœba in side view. A, anterior end; P, posterior end. The large arrow above shows the direction of locomotion; the other arrows show the direction of the protoplasmic currents, the longer ones representing more rapid currents. From a to x the surface is attached and at rest. From x to y the protoplasm is not attached and is slowly contracting, on the lower surface as well as above. a, b, c, successive positions occupied by the anterior edge. As the animal rolls forward, it comes later to occupy the position shown by the broken outline. (*Jennings.*)

Locomotion is quite free in the amœba, but cells may lack locomotory power and still be amœboid; *i.e.*, capable of changing their shape. Thus many of the radiolaria and foraminifera being inclosed in mineral shells cannot move from place to place, though they commonly extend pseudopodia, which are sometimes extremely long and delicate, through the minute openings of their shells.

The cells of the more simple metazoa retain a limited amœboid movement, and in the highest animals amœboid cells may still be found. The best known of these is the white blood corpuscle (polymorphonuclear).

Under abnormal conditions many of the fixed cells of the higher animals show that they retain the amœboid movement to a limited extent.

Ciliate and *Flagellate Movements.*—Cilia are minute short hair-like processes with which many cells are provided; flagella, larger, coarser, whip-like processes. Between the two there is no sharp line of distinction, and the numerous cilia of the bacteria are universally known as flagella.

FIG. 22.—*Amœba verrucosa* coiling up and ingesting a filament of oscillaria, After Rhumbler (1898). The letters *a* to *g*, show successive stages in the process. (*Jennings.*)

Cilia and flagella are specialized processes of the cell substance, composed of hyaloplasm. They are analogous to pseudopods, but differ from them in their more uniform and delicate structure and in being permanent instead of temporary structures. They can be made use of to assist in the classification of many organisms.

Cilia are utilized for the double purpose of motion and locomotion. Thus many of the infusoria are covered with minute hair-like cilia of uniform size, whose synchronous vibrations propel the organisms

at a fair rate of speed through the fluids in which they live. These are locomotory in function. It is interesting to observe that they may vibrate synchronously in a given direction, or vibrate on one side of the body more rapidly than on the other so that the direction may be changed, or may reverse their direction so that the organism may move backwards. When organisms like Paramœcium conjoin, their cilia vibrate synchronously so that they easily swim along together. As has been shown in speaking of galvanotropism, the direction and movement of the cilia may be modified by electric currents.

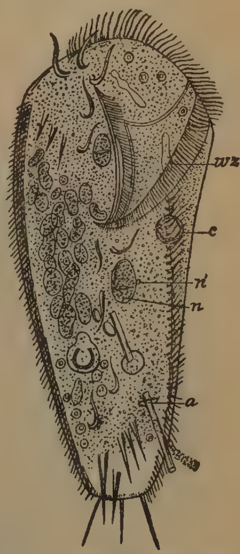

FIG. 23.—Stylonychia mytilus: *wz*, Cilia about the mouth opening; *c*, contractile vacuole; *n*, nucleus; *n'*, para-nucleus; *a*, anus. (*Clau's Zoology.*)

Many organisms are provided with cilia about the oral opening, vibration of which causes currents of water to flow toward the mouth so that objects adapted for food are readily caught. Cilia of this kind are usually longer than those used for locomotion. Beautiful examples are found in Rotifers.

Cilia also occur upon the cells of higher animals where they subserve different purposes in the economy of the animal without being of particular benefit to the cells themselves. Thus the ciliated cells of the gills of lamellibranchiata bring currents of fresh sea-water to the gills of the animals and so facilitate the aeration of its blood.

The respiratory passages of vertebrates are lined with ciliated epithelium whose rhythmical vibrations assist in

Fig. 24.—Spiral path of Paramœcium. The figures 1, 2, 3, 4, etc., show the successive positions occupied. The dotted areas with small arrows show the currents of water drawn from in front. (*Jennings.*)

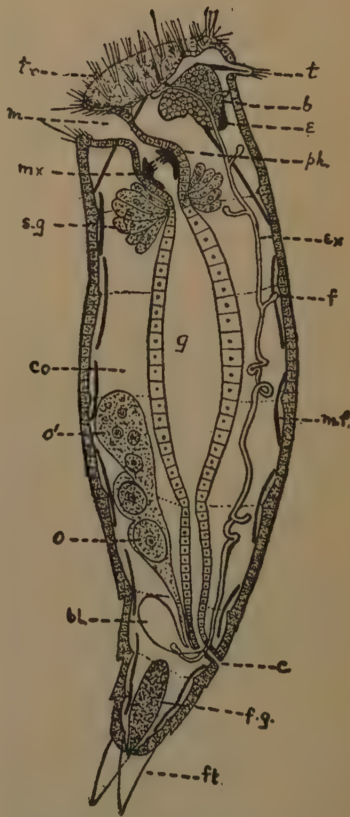

Fig. 25.—Diagram of a sagittal section of a Rotifer. *b*, Brain; *bl*, excretory bladder; *c*, cloaca, the common opening of digestive and reproductive organs; *co*, *cœlom*; *e*, eyespot; *ex*, excretory canal; *f*, flame cells; *f.g*, foot gland; *ft*, foot; *g*, gut; *m*, mouth; *m.f*, longitudinal muscle fibres; *mx*, mastax; *o*, ovary; *ph*, pharynx, *s.g*, salivary gland; *t*, tentacle; *tr*, trochus, or cilia-bearing disc. (*Galloway.*)

removing minute inhaled particles from the deeper portions of the respiratory tract.

The Fallopian tubes are also lined with cilia whose lashings directed toward the uterus facilitate the passage of the mature ovum from the ovary to that viscus.

Flagella are longer coarser processes not clearly differentiable from cilia, but usually occurring in smaller numbers. As has been said, custom sanctions the use of the word flagella in regard to the cilia of bacteria. In

Fig. 26.—Trypanosoma lewisi. A flagellate parasite of the blood of the rat. × 1000.

these lowly vegetable organisms they may appear like cilia in that they sometimes arise from all parts of the surface of the organism or like the flagella of the protozoa in that they arise from one or both ends of the cell.

In the flagellata they may also arise from one or both ends, and may be single or multiple. In the highly motile forms of flagellate protozoa, such as the trypanosomes, they usually project anteriorly and possess a spiral movement by which the animal is drawn through the fluid medium in which it lives.

There is but one flagellated cell in the higher animals, the spermatozoon, in which the single flagellum, called the tail, propels the cell like the tail of a tadpole and follows the body or head. The purpose of the flagellum is to enable the spermatozoon to ascend the reproductive passages (Fallopian tubes) until it meets the ovum for fertilization.

Contractile Movements.—Certain cells undergo a physiological specialization, by which they are enabled to contract and so produce movements advantageous to the cell. It is difficult to determine exactly where this function begins. It might be attributed to the amœba and explain the withdrawal of its pseudopodia were it not impossible to find any evidence that these processes in any manner differ from the remainder of the cytoplasm.

In vorticella we see a pedicle or stalk consisting of an extension of the cytoplasm (ectoplasm) endowed with active contractile powers, and showing a peculiar spiral structure to account for it.

In many hydras the tentacles are armed with nettle-cells or stinging cells, irritation of which causes the sudden projection of fine stinging cells by which the prey of the animal is paralyzed. When the stinging function is performed, the hair-like process is again withdrawn through a contractile specialization of that part of the cell.

As the scale of animal complexity is ascended and increase of size and differentiation of structure becomes more and more marked, the necessity for special mechanisms by which the necessary movements for carrying on the functions is more imperatively experienced, special cells and groups of cells become endowed with a structure adapting them for contraction. These are known as muscle cells and eventually lose most of their cellular characteristics through the differentiation of their substance into fibrillæ composed of alternating discs, chemico-physical disturbances of which result in lengthening or shortening and thus in movement.

So complex does this structure become in the higher animals that the exact nature of the contractile phenomena has not yet been explained.

METABOLISM.

The early students of biology believed that the vital manifestations depended upon a special force—vital force—peculiar to living substance. A few still adhere

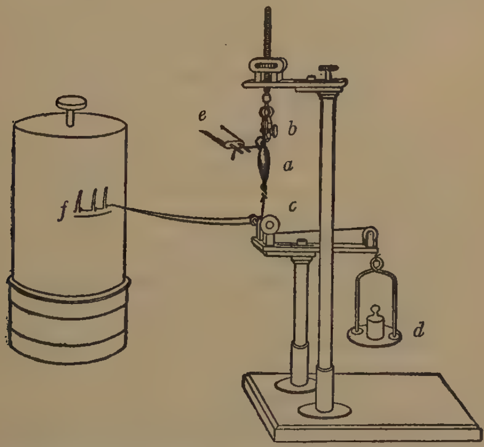

FIG. 27.—Myograph, an instrument used for recording muscular contractions. A frog's muscle *a*, is fixed by one end in the holder *b*, while a thread *c*, is fastened to the other tendon, connecting it with the weight, *d*. When the electrode *e*, stimulates the muscle, the movement is recorded upon the revolving drum, *f*. (*Verworn.*)

to this belief and are called, in consequence, *vitalists*, but an ever-increasing majority see in them nothing that may not be explained by the ordinary laws of chemistry and physics and are therefore known as *chemico-physicists*.

When the activities of living substance are carefully studied, it is easy to determine that every activity, being an expenditure of energy, is attended with molecular (chemical) changes in its composition, usually in the form of oxidation and analogous to the process of com-

bustion. We are, therefore, led to the conclusion that the chemical activities are the source of the energy, and that all vital manifestations are physico-chemical in nature.

The phenomenal differences between vital and non-vital substance is found in the self-constructive and self-sustaining character of the former.

As has been shown in a former chapter, there is no evidence that living substance is at present self-existent. All known forms spring from antecedent forms of like kind whose origin is as unknown as the origin of matter and force. But such forms of living matter as are known begin life in a very humble form—mere specks of protoplasm constituting the spores, seeds, or eggs of their parents—though endowed with the phenomenal self-sustaining and self-constructive powers.

Remembering that every activity, being an expenditure of energy, results in oxidation, and this in alterations in molecular composition, we wonder to see no visible result ensue. The secret of this lies in the wonderful power of adjustment by which the molecular disturbances are immediately compensated for by internal rearrangements of the molecules.

If the activities be increased by stimulation, we find that the compensatory readjustments are of limited extent and duration, and the organism ceases to respond. It is fatigued, or it rests, or it enters a state of vital rigidity. If left to itself for a time, the adjustments take place and activities begin again, showing that the organism still lives.

Suppose, however, the stimulation be of such nature as to compel the organism to activities of more prolonged duration, attended with greater oxidation and greater molecular disturbance, and the point is soon reached when the possibility of internal adjustment ends and reaction to the stimulant ceases not because it is temporarily embarrassed by the necessity for adjustment, but because adjustment has become impossible.

When we inquire into the meaning of the continuous activity of normal life, as contrasted with the temporarily suspended activity of fatigue and the permanently suspended activity of death, we find it explainable through a study of the nutritive or self-sustaining power of the organism.

Ordinary activity, exaggerated activity, exhausting and fatal activity, being followed by varying degrees of molecular disturbance through combustion, necessitate varying degrees of molecular reintegration; *i.e.*, the introduction of new matter to replace what has been lost.

Such new matter constitutes the *food* of the organism. A food may therefore be defined as any substance from which a living organism is able to derive material for its sustenance or increase.

It is a common observation that organisms beginning their life histories as microscopic masses of protoplasm eventuate in enormous numbers of simple or in enormous masses of complex kind. This shows the natural disposition of living substance to increase. Such increase of numbers or size being possible only through increase in the actual quantity of the living substance, it becomes clear that that substance is endowed with the capacity of forming more substance of its own kind.

Living substance or protoplasm is the most complexly compounded of all the substances known to the chemist. Indeed it is so complex in chemical structure that its exact composition is unknown and no correct formula for it has been worked out.

Protoplasm stands at the head of a list of compounds known as proteins, some of which are well-known, yet not one of which is correctly known as regards its true chemical composition. The reason becomes obvious when a few of the formulæ suggested are examined. Thus one chemist who studied the hemoglobin from the dogs' blood finds it represented by the formula $C_{726}H_{1171}N_{194}O_{214}S_3$. One of the various formulæ suggested for egg-albumen is $C_{204}H_{322}N_{52}O_{66}S_2$. The com-

plexity is so great that no two chemists arrive at the same result. If such is the complexity of fixed and relatively stable egg-albumen, how much more elaborate the structure of the subtle and evanescent living protoplasm must be we can scarcely conjecture.

Gustav Mann, however, very properly points out that we may fall into error in this particular. He says: "To many people a living cell consists of 'protoplasm,' a substance they imagine to be one exceedingly complex body. They do not realize that in a cell we have a not very large number of comparatively simple compounds which only collectively form the protoplasm. What constitutes life is the presence of a number of such 'organic' compounds capable of mutually reacting upon one another, and thereby giving rise to new compounds, which cannot react chemically with the mother substance from which they are derived, but which by interacting with new radicals give rise to a cycle of events."

To learn the process by which protoplasm is built up, one might imagine that the simplest method would be to follow the successive steps in its disintegration, learn its products of analysis, and then, by retracing the steps from the simple to the complex, arrive at an approximately accurate result.

It is true that when protoplasm dies it undergoes a speedy dissolution, terminating in a number of well-known simple compounds, but though the stages in the disintegration process seem to be so brief, the successive steps pass through an enormous series of transformation products so rapidly, that they cannot be followed.

Indeed, if we start with a relatively stable protein, like egg-albumen, and endeavor to resolve it into less and less complex compounds, we still find ourselves working with a complexity yielding many series of compounds until we are lost in an impenetrable physiologico-chemical labyrinth, beset on every side with a polysyllabic nomenclature that only increases our bewilderment.

We cannot, therefore, in the present state of knowledge pretend to follow the elaborate synthesis of living matter. We can, however, analyze that matter and discover the elementary substances of which it is composed, and this has been done again and again with interesting and important results.

Thus an analysis of vegetable cells shows them, without exception, to be composed of C, O, H, N, S, P, K, Ca, Mg, and Fe, while similar analyses of animal cells yield C, O, H, N, S, P, K, Ca, Mg, and Fe, found in the vegetable cells, and in addition Na, Cl, I, and Si.

It would, therefore, seem that vegetable life is less complicated than animal life, and also that it is more easily carried on.

It must not be supposed that the elements mentioned comprise the full list of all that may be found in either vegetable or animal tissues; instead they form the indispensable list to which others may be or commonly are added with advantageous results to the particular organisms. Thus, for example, Si is not enumerated among the vegetable components, yet it is frequently present and benefits a plant by increasing the rigidity of its tissues.

If living substances, either animal or vegetable, require at least ten elementary substances for the elaboration of their tissues, it is evident that they cannot perform their vital functions when the supply of these elements fails.

It is also evident that no substance can be so well adapted for the supply of the essential elements, in the most useful combinations, as living substance itself, which explains why living beings of the highest kind so universally live upon living things of other kinds. The next most useful material would be that which had been living, but is in process of dissolution into similar compounds of still assimilable quality.

It is, however, evident that primordial forms of life could neither feed upon antecedent life or its derivatives,

hence we find at the bottom of the scale of living things, forms that are able to seize upon relatively simple inorganic compounds combining them into more and more complex compounds and integrating them into living protoplasm, while at the top of the scale of life we find organisms whose appearance must have come relatively late in time, that are unable to make use of any of the simple inorganic substances, and are absolutely dependent upon the lower antecedent forms for food.

How the animal substance reintegrates itself and builds up additional animal substance by appropriating to its uses the equally complex substance of other individuals or the slightly less complex products of their disintegration, it is beyond the knowledge of chemists to give any adequate information, for we neither know the nature of the substance being integrated nor that of the substances by which it is being integrated.

On the other hand, when we inquire how the more simple vegetable organisms are nourished, the problem is simplified, for, though the vegetable protoplasm is still too complex for us to follow in its transformations, the compounds with which and upon which it works are so simple and so well-known that we can easily follow them through many transformations. In doing this, however, we find the living substance capable of performing miracles of chemical synthesis, the experimental reproduction of which is impossible.

Of the numerous elements that are said to enter into the composition of living substance many have been mentioned that find no place in the hypothetical structure of the proteid molecule. It is by no means certain that these elements find a place in the composition of protoplasm. They are discovered by an examination of masses of tissue composed of protoplasm and its numerous products, not by examination of the elementary substance itself. A single elementary mass of protoplasm—a cell—is so small and the quantity of these elements so minute that they must inevitably elude

detection. It is not known, therefore, whether they are present or not. It is, however, known that it is only in the presence of these elements that the functions of life can be carried on. In the vegetable world this is so fundamental in importance that if a single one of these elements—S, P, K, Ca, Mg, and Fe—is absent, normal development is impossible.

It is supposed that the living matter—protoplasm—is purely protein in character, and consists, like egg-albumin, hemoglobin and other proteins, of some combination of C, H, O, N, and S, and that the additional elements serve as electrolytes by which its functions are carried on.

When we come to study the materials out of which protoplasm can be built up, most interesting experimental studies in plant life are available.

Thus Proskauer and Beck found that the tubercle bacillus, one of the bacteria, or lowest forms of vegetable life, can grow well in a mixture consisting of:

Commercial ammonium carbonate (NH_4HCO_3)	0.35
Primary potassium phosphate (K_2PO_3)	0.15
Magnesium sulphate ($MgSO_4$)	0.25
Glycerin ($C_3H_8O_3$)	1.5
Water (H_2O)	ad 100.

Raulin made a most painstaking study of the nutrition of a mould, Aspergillus niger, testing it in every possible way and finally discovering that its maximum growth took place in a solution containing:

Water	1500.00 grams
Cane-sugar	70.00 grams
Tartaric acid	4.00 grams
$(NH_4)_3PO_4$	0.60 grams
K_2CO_3	0.60 grams
$MgCO_3$	0.40 grams
$(NH_4)_2SO_4$	0.25 grams
$ZnSO_4$	0.07 grams
$FeSO_4$	0.07 grams
K_2SiO_3	0.07 grams

So precise was this work of Raulin, that he found the least variation in any of these ingredients produced a

quantitative difference in the weight of the dried residuum of mould secured.

If we wish to study plant nutrition and discover out of what materials the substance of the growing organism is elaborated, it can be done with exactness by means of a *water culture.* This consists of distilled water to which are added known quantities of such compounds as are essential to the life processes of the plant. v. d. Crone recommends the following solution which is one of the best:

Distilled water	1000–2000 c.c.
Potassium nitrate	1 gram
Ferrous phosphate	0.5 gram
Calcium sulphate	0.25 gram
Magnesium sulphate	0.25 gram

An examination of these ingredients will discover the S in two, P in one, K in one, Ca in one, Mg in one, and Fe in one, thus this solution furnishing all of the electrolytes essential to plant life, a seed or spore moistened with it is able to set in motion those chemical processes by which its integration is effected. Some of the essential elements of the protein of the protoplasm are, however, conspicuous by their absence, Where, for example, are the O, H, and C? There are two sources from which these may be obtained, O from the atmosphere into which the plant grows, H from the water into which its roots extend, and in each of which more or less CO_2 is dissolved and may yield the C.

Absorbing the H_2O, the CO_2, and the O, the germ of living substance, by virtue of the powers it already possesses, with the aid of the electrolytes with which it is supplied in the solution, begins operations by combining these molecules to form more complex compounds, some of which it no doubt immediately carries further through intermediate steps to the actual plant protein, some of which it stores up for time of future need, and some of which it uses for the scaffolding in which its increasing active substance is to be supported and by which it is to

be protected. It is possible to follow what are presumably the successive steps in the formation of one of the best-known of the vegetable products, starch. Thus, in conditions such as prevail in the water culture, to which reference has been made, we have found available for use O in the air, water (H_2O) in which the salts required are dissolved, and CO_2 in both the air and water, in small quantities. We have, therefore, O, H_2O, and CO_2 to work with. The first step in the process seems to be the extraction of the C atom from the CO_2 and its addition to the H_2O molecule thus:

$$CO_2 + H_2O = CH_2O \text{ (formic aldehyde)} + O_2.$$

If we study plant photosynthesis, we find that this actually takes place, for in the gases given off by a plant we find an increase in the O which can only be accounted for by the abstraction of the C from the CO_2.

FIG. 28.—Water cultures of *Fagopyrum esculentum*. I. In nutrient solution containing potassium; II. in nutrient solution without potassium. Plants reduced to same scale. (*After Nobbe.*)

As we continue the synthetic process we find:

$$6CH_2O = C_6H_{12}O_6 \text{ (monosaccharide)}$$

formed by a rearrangement of atoms to make a more

complex molecule, and then a still more complex arrangement:

$nC_6H_{12}O_6 - nH_2O = (C_6H_{10}O_5)n$ (starch and cellulose) by which starch and cellulose are made.

At this point we reach products capable of subserving many different purposes. Doubtless further more complex syntheses are immediately effected, though the cellulose being a structural element of importance to the plants is commonly deposited in permanent form where needed, and the starch is temporarily deposited in scattered granules or in dense aggregations, as in potatoes, peas, beans, fruits, etc., until needed for further transformations.

At this stage we reach also the point at which the utilization of the plant products by animals becomes possible, starch forming one of the most valuable foods of the higher animals.

Beyond this point the progress of the synthetic process can no longer be followed, because the complexity of the molecular compounds becomes too great.

REPRODUCTION.

As living beings are subject to such wear and tear as results from their activities and to accidents of various kinds, the persistence of life is dependent upon the ability of living substance to reproduce its own kind, Reproduction is, therefore, a fundamental manifestation of life.

The new individual, no matter how produced, is endowed with potentialities and possibilities the sum of which constitute *youth* and, therefore, constitutes a new *generation* qualified to repeat not only the structure, but also the functions of its parent.

As will be shown in a future chapter, the particular form of reproduction varies with the simplicity or complexity of structure, yet all forms of reproduction are ultimately referable to simple phenomena, such as are

seen in the most simple forms of life—*i.e.*, the cells—and consist of *cell-division*. This is a manifestation the cause of which has long been sought by biologists with little success. It was at one time supposed to depend upon some simple physical condition and even attributed to disproportions between the absorbing surface through which the cell was nourished and the amount of cell contents to be nourished.

Thus, as a cell grows the contents increase in three dimensions while the surface increases in but two. It was supposed that when a certain cubical content was reached, the cell became embarrassed by its inability to secure nourishment and so was compelled to undergo some compensatory change, the most frequent being division. This explanation is, however, inadequate, for among cells whose nourishment is effected through the intracellular digestion of ingested food particles it could not apply.

It would seem, therefore, to be a hereditary peculiarity of the cell and to be determined by chemical conditions intrinsic in the cell itself.

This inability to fully comprehend the conditions leading to multiplication or reproduction forbids an intelligent understanding of the process and limits us to the description of what is to be seen without enabling us to explain it.

References.

O. Hertwig: "Die Zelle und die Gewebe," Jena, 1892, 1905
Max Verworn: "Allgemeine Physiologie," Jena, 1909.
H. S. Jennings: "Behavior of the Lower Organisms," N. Y., 1906.
Jacques Loeb: "The Dynamics of Living Matter," N. Y., 1906.
E. Strasburger, H. Schenck, F. Noll, and G. Karsten. "A Text-book of Botany," Third English Edition by W. H. Lang, N. Y. and London, 1908.

CHAPTER V.

THE CELL.

The most simple living beings consist of single structures, *i.e.*, *cells*, and are known as *protozoa* when of animal nature, *protophyta*, when of vegetable nature. More complex beings are composed of an increasing number of cells which eventually become innumerable. Such are known as *metazoa* and *metaphyta*, respectively. An analysis of structure thus leads to the cell as the unit, and before complexly organized beings can be understood a knowledge of cells becomes imperative.

Until the nineteenth century, microscopy had not reached a point at which it was able to place satisfactory interpretation upon the minute structure of either plants or animals. This came in 1838 when Schleiden, a German botanist, showed that vegetable tissues were composed of various combinations of more or less similar living units formed in a true and orderly manner, and Schwann discovered the same to be true for animals.

The living—vital—nature of the structural units formed the basis of Kölliker's new science of histology, became the foundation of a new conception of physiology in the hands of Verworn, and was made the basis of modern pathology by Virchow.

The cell was originally conceived to be an anatomical unit, and it was supposed that all cells presented more or less uniformity of structure; but it is now known that their structures may be quite dissimilar. Indeed, this dissimilarity of structure admits such latitude into the concept "cell" that it becomes almost impossible to define it. As here used, the term cell signifies a struc-

ture capable of displaying all of the vital manifestations. but not capable of resolution into simpler vital structures,

The cells, thus understood, vary widely among themselves as to size, morphology, independence, and function.

In regard to size, there is an enormous difference. Some cells, as the bacteria, are so minute as to be visible only to the highest powers of the microscope, and there is every indication that there are cells so minute that no microscope thus far invented can define them. Other cells, as certain eggs, are large enough to be visible to the naked eye without difficulty. Size is, therefore, an unimportant quality of the cell.

In morphology the cells differ almost as widely as in size. Certain of the most lowly forms of life consist of microscopic specks of protoplasmic jelly in which no definite structure can be made out, so that it has long been controversial whether they are provided with even so important an organ as a nucleus. Other cells, such as the mammalian ovum or egg, are complexly constructed and provided with many well-known and clearly defined parts.

Taking the mammalian ovum as a good type for study, we find it conforming to the primitive conception from which the term "cell" was derived; *i.e.*, it is a globular or spherical mass of living substance, shut in by a definite envelope, membrane, or "wall." This primitive idea of all cells being definitely inclosed by a "wall" has long been abandoned, for it is now well known that there are many more cells without than with such a structure. What is true of the cell wall or membrane is true of all the cell structures except the protoplasm and the nucleus. There are no cells without protoplasm, and it is controversial whether there are cells without a nucleus. There are, however, cells in which no nuclei have yet been seen.

Taking it for granted that our inability to recognize a nucleus in certain cells is evidence that none exists, we find the most primitive form of cell to be a minute

undifferentiated speck of protoplasmic jelly. This shows us that the protoplasm or *cytoplasm*, as it is now usually called, is the essential living substance. Many attempts have been made to show that the cytoplasm is of definite texture, but it is now pretty generally conceded that it consists of a structureless matrix or clear jelly, the *hyaloplasm*, in which certain granules, the *spongioplasm* or polioplasm, are suspended. It is because of the presence of the spongioplasmic granules that cytoplasm almost invariably appears granular.

The granules are of various quality, as is shown by their diverse micro-chemical reactions. This is well shown by an examination of human white blood corpuscles treated with a mixture of colors, such as make up Ehrlich's, Biondi's, Wright's, Jenner's, or Romanowski's stains. When a carefully prepared film of human blood is stained with one of these reagents, we find the white corpuscles showing certain variations that enable them to be assigned to well-marked classes. Thus, about 70 per cent. show a cytoplasm rich in granules that have assumed a purple color, and are known as neutrophilic granules; about 25 per cent. are without granules and are called hyaline cells, and the remainder are chiefly made up of cells filled with coarse round granules that stain a brilliant red color—the eosinophile cells.

It may naturally be inferred, and the inference is probably correct, that these diversely reacting granules are different in nature and function, though it has not been determined what the office of the granules is. Altman, who first described cytoplasm as granular, called the granules *bioblasts* and conceived that they were the actual source of the cell life; but his view has been abandoned, and we now suppose that the granules of the spongioplasm are composed of those substances formed by the living substances and useful in its various activities. From this point of view these granules are not permanent structures, but appear and disappear as they are prepared or employed.

It is further found difficult to say what granules actually belong to the substance of the cytoplasm or may be temporarily harbored by it. Thus in many cells of the higher animals we find granules that are reserve stuffs held by the cells until needed elsewhere. In the cells of the resting salivary gland large numbers of granules are found which are absent after the gland has been for some time active. These granules, used up during the

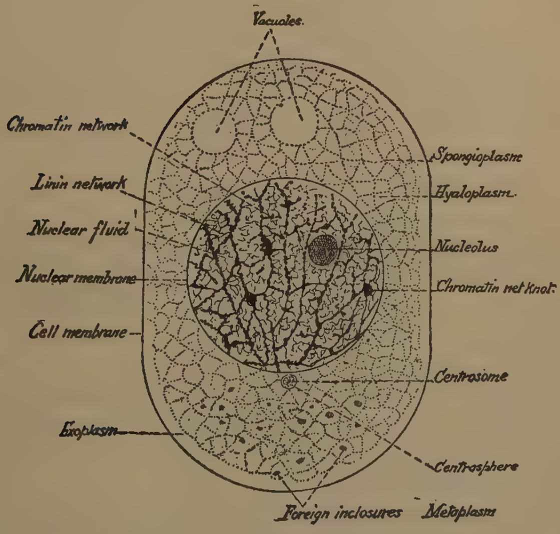

FIG. 29.—Diagram of a cell. (*Huber.*)

glandular activity, were composed of the antecedents of substances supplied by the cells to the glandular secretion, were products of cellular activity, but were not components of the essential vital structure of the cytoplasm. In the cells of the liver it is common to find globules of fat and glycogen especially after a meal rich in fats and carbohydrates, but being temporarily present they cannot be essential components of the cytoplasm.

In the larger free cells, such as amœba and paramœcium, we find granules (*physodes*) of temporary occurrence which are probably the not yet utilized products resulting from the intracellular digestion of the smaller entities upon which the organisms feed.

In vegetable cells there is even less difficulty in differentiating certain large coarse granules not essential components of the cytoplasm, yet contained in that substance and destined for the performance of definite functions. These are the *chromatophores*, which are the antecedents of the *chloroplasts*, by which chlorophyl is formed, and the *chromoplasts* by which are elaborated the pigments by which the flowers and fruits are colored. Plant cells also contain *starch* and *aleurone* granules in many cases. Many plant cells are also distended with sap which takes the form of vacuoles that soon become too large to be mistaken for granules.

It is thus seen that the cytoplasm is not only granular because of its spongioplasm, but also because of adventitious granules constituting the *deutoplasm* or *paraplasm*, matters temporarily contained in it.

It must, however, occur to the student that there is no criterion for the separation of paraplasm and spongioplasm other than our ability to recognize the nature and purpose of the latter and our inability to do so with regard to the former.

The second essential structure of the cell is the *nucleus*. In its most highly developed form this is a highly complex organ. It appears as a spheroidal protoplasmic body whose size bears a fairly constant relation to the size of the cell though the proportion differs greatly in cells of different kinds. It is usually enclosed in a hyaline membrane, known as the nuclear membrane, and consists of substance divisible into a part that is structureless and probably fluid, known as the nuclear juice, or *karyoplasm*, and material that is for the most part filamentous and known as the nuclear substance or *karyomitome*. Staining reagents show that the struc-

tures comprising the nucleus are chemically different from those of the cytoplasm, and a large part of the science of histology has been the result of observations made upon cells and tissues subjected to what is called nuclear staining.

The microchemic study of the nuclear structures has not been very useful, except that it has shown them to be dissimilar in composition. The nuclear membrane is said to consist of *amphipyrenin*, the *karyoplasm* of *paralinin*, and the *karyomitome* of two substances, one of which does not react with the stains, and is called *linin*, the other with a strong affinity for all nuclear stains, being known as *nuclein* or *chromatin*. In some nuclei a small distinct body or *nucleolus* occurs. It is composed of *pyrenin*.

Of these various structures the nuclein or chromatin is of paramount importance, being composed of a number of units, distinctly visible only at the time of cell multiplication and known as *chromosomes*. Much will be said of these bodies in connection with karyokinesis or nuclear division and in considering the problems of heredity.

The great majority of cells possess a single nucleus; some of the unicellular organisms, as the protozoa are provided with two, the larger and more distinct being known as the *macronucleus*, the smaller and less conspicuous as the *micronucleus* or *paranucleus*.

Some lowly organisms of considerable size consist of masses of undifferentiated protoplasm containing many nuclei. Such are known as *plasmodia*, and in some cases as the myxomycetes, are known to be formed by the coalescence of many cells.

The cells of the metazoa and metaphyta rarely contain more than one nucleus, the striking exception being the bone corpuscles or *myelopaxes* found in the red marrow.

The shape of the nucleus, though usually spheroidal, may vary. In elongate cells it is highly prolate, and in cells subject to much compression may be distinctly oblate. In old cells the nuclei may be irregular in

shape. Rarely in the cells of certain arthropods the nuclei may be branched or even reticular. Diseased cells may also show breaking up or fragmentation of the nucleus—*karyorhexis*—or solution of the nuclear materials—*karyolysis*.

The *cell wall* that formed so essential a part of the primitive conception of the cell is an extremely variable structure. The lowest forms of life are commonly with-

Fig. 30.—Cells with variously shaped nuclei. *a*, Vorticella, a ciliated infusorian with a sausage-shaped nucleus. *b*, Stentor, a ciliated infusorian with a rosary-like nucleus. *c*, Cells from the silk glands of a caterpillar, with nuclei branched like stag's antlers. (*After Korschelt.*)

out it, and the greater number of the cells of the metazoa are without it.

In its most primitive form one sees nothing but a transparent hyaline border to an elsewhere granular cytoplasm. Under these conditions it is sometimes spoken of as the *ectosarc*, to differentiate it from the *endosarc* or cell substance. As the evolution of the structure is followed, it is found that it modifies certain of the physiological manifestations of the cell. Thus, the amœba

that has no true cell wall is actively amœboid and appears able to take in food particles through any part of its surface. In more highly specialized protozoa (corticata), such as Paramœcinum, Kerona, and Vorticella, there is a well-defined somewhat rigid cell envelope which prevents amœboid movement and determines that food can be ingested only at a given point in the body surface—the oral aperture.

In certain encysted cells, such as coccidia, the cell wall becomes a dense tough thick structure able to resist drying and other unfavorable conditions, and in the spores of bacteria the resisting power of the cell wall is still more highly developed.

The ova of tape-worms are not only surrounded by a very tough cell wall, but this in turn by a layer of mucous.

The mammalian ovum has a highly developed cell wall known to histologists and embryologists as the *zona pellucida.* It is a thick, hyaline structure, has numerous projecting short filaments, and appears to have many perforations large enough to admit the head of a spermatozoon.

The highest development of the cell wall is, however, found in the metaphyta or higher plants, where, however, it becomes a product of the cell rather than an integral part of it. Growing plant cells have very thin walls, but so soon as the cells have attained their full size, the cell wall begins to increase in thickness, first by intussusception and later by the deposition of new layers upon the originally formed wall. In this process cellulose is the primary product, pectin, lignin, and suberin being secondary products later deposited. The vegetable cell, in the sense of protoplasmic mass, thus comes to lie loosely in a circumscribed space, the walls of which are of its own formation, but to which it is not indissolubly bound and of which it is not itself a part.

Thus it appears that the botanist and the zoologist mean somewhat different things when they speak of the cell wall.

Many cells contain a small rounded body known as the *centrosome.* It is subject to many variations. Sometimes it appears shortly before cell division is to take place; sometimes its presence is invariable.

The source and function of this body are unknown. It is in some manner connected with multiplication, for it always divides before the other structures of the cell, and in many cases it disappears shortly after the process of cell division has been completed.

Vacuoles are frequently present in the cells. The term is applied to what seem to be empty spaces in the cytoplasm. They are most frequent and largest in vegetable cells during active growth and then are really drops of sap with which the cytoplasm distends itself during the process of nutrition.

In animal cells similar vacuoles are to be found and are probably formed by the local collection of the products of digestion awaiting assimilation. In certain of the protozoa these products appear to collect in preformed spaces which communicate with one another so that the contents of one may be expelled into another. In some of these animals there is a ryhthmical to-and-fro movement of the fluid from one vacuole to another, *contractile vacuoles.* It is supposed that the movement of the fluid aids in assimilation through the acceleration of cytoplasmic circulation.

Vacuoles not infrequently consist of reserve stuffs temporarily stored in the cells. Of such nature are the globules of fat and glycogen so commonly found in the liver cells of man and the enormous fatty globules in the fat-storing organs and subcutaneous tissue of the higher animals.

CHAPTER VI.

CELL DIVISION.

The most simple form of reproduction or multiplication takes place through the separation of the cell into two or more segments of fairly uniform size and appearance.

It is usually preceded or accompanied by remarkable changes in the nucleus which have led to its being called *karyokinesis*, *karymitosis* or *indirect cell division.* The appearances vary according to the simplicity or complexity of the cellular structure so that one description cannot apply to all cases, though an account of what takes place in a typical cell may be accepted as a type of the process.

The cell that is about to divide is distinctly larger than its fellows and its nucleus contains an excess of nuclein or chromatin—*hyperchromatosis.* The cells formed by division are smaller than the normal, so that both before and after division we see examples of true cell growth with actual increase of the essential substances of the cell.

It will be convenient for our present purposes to divide the karyokinetic changes into the following phases:

1. *The Preparation of the Nucleus for Division.*—When an ordinary resting nucleus stained by the usual methods is carefully observed it will be found that the nuclear membrane is quite distinct, and that just within it there is a more or less well marked, slightly filamentous deposit of chromatin. The remainder of the nucleus is brilliant and clear, with scattered threads of chromatin. If a nucleolus be present it appears as a minute

distinct dot. As the chromatin increases in quantity prior to division it comes to fill the greater part of the nucleus and the nucleolus disappears. Soon the chromatin increases in filamentousness until a single long somewhat spirally coiled thread—the *spirem*—is found. When examined under most appropriate conditions this thread has a fuzzy appearance which is supposed to depend upon an incomplete differentiation of the chromatin from the linin, which clings to it. Soon, however, the linin

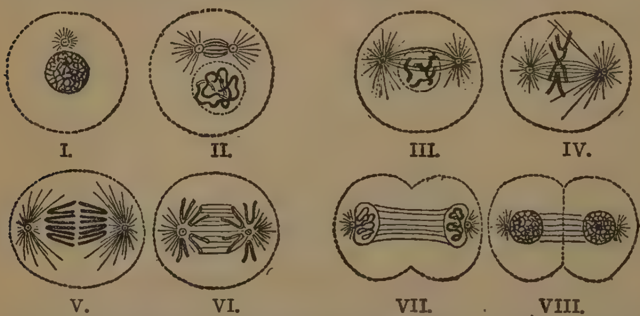

FIG. 31.—*Karyokinesis* of a cell with four chromosomes. I, Resting nucleus with centrosome above. II, Formation of the spirem, and beginning division into chromosomes; division of the centrosome and formation of the nuclear spindle. III, Elongation of the nuclear spindle to the poles of the cells; division into chromosomes complete. IV, Longitudinal cleavage of the chromosomes. V, Separation of the chromosomes. VI, Complete separation of the chromosomes which are clustering about the centrosomes, forming daughter stars. VII, Double spirem formation and beginning division of the cytoplasm. VIII, Daughter cells resulting from the completed changes. (*After Schaeffer.*)

separates completely, after which it is observed that the chromatin no longer forms a single thread, but has broken into a number of segments of uniform length, which are the *chromosomes*. These bodies are of great interest from many points of view, and are believed by Weismann and others to endow the offspring of the cell with its chief hereditary impulses. The number of chromosomes is exactly the same in all cells of the same kind, though it varies in different kinds of cells. In complex organisms there is also a difference between

the number of chromosomes in the somatic and germinal cells, the latter having twice the number of the former. For example, the somatic cells of human beings, oxen, and guinea-pigs have all sixteen chromosomes, the germinal cells thirty-two; the somatic cells of the mouse, salamander, and trout twenty-four, the germinal cells forty-eight; the somatic cells of ascarides two, their germinal cells four.

About the time that the chromosomes become distinct it can also be determined that each has undergone a longitudinal cleavage into two parallel threads of exactly equal size.

In cells in which no centrosome is usually visible, that organ now makes its appearance surrounded by a condensed or highly granular area of cytoplasm known as the attraction sphere, which is to become the "polar field."

2. *The Disappearance of the Nuclear Membrane and the Division of the Chromosomes.*—During these changes the nuclear membrane has imperceptibly disappeared leaving the chromosomes free in the cytoplasm. The chromosomes in the meantime have uniformly assumed a V-shape and arranged themselves about the polar field with the apices toward the centre. It now makes considerable difference from which direction one views the groups of chromosomes, for at the same time that this adjustment has been in progress the centrosome has divided and its halves have gradually separated so that we have now a "polar field" and a "hypopolar field," each occupied by a centrosome from one to the other of which delicate filaments of linin extend forming a peculiar object known as the "nuclear spindle."

If the group of chromosomes be viewed from a direction corresponding to the polar or hypo-polar fields, one sees those bodies with their apices directed toward the centre, their ends outward, forming an appearance sometimes compared to a wreath, but usually to a star and spoken of as the "mother star." If, on the other

hand, they are viewed from a point at right angles to the axis of the nuclear spindle, it will be found that they all lie in a plane perpendicular to the axis of the spindle known as the "equatorial plane."

3. *The Separation of the Chromosomes and the Formation of Daughter Stars.*—The chromosomes, which it will be remembered have undergone a longitudinal cleavage, now manifest a phenomenal change of position. Beginning at the centre, each half moves from its fellow and directs itself toward one end of the nuclear spindle until there has been an exact division of the filaments, one-half having gradually moved into the polar field, the other half into the hypopolar field.

This results in the formation of a double figure, the *amphiaster* or "daughter stars." Each of these exactly resembles the aster or mother star except that its size is smaller.

During this phase of the nuclear changes the cytoplasm shows an increasing constriction in the line of the equatorial plane which progressively deepens so that about the time that the nuclear changes are perfected the separation into two cells is also completed.

4. *The Transformation of each Daughter Star into a Perfect Nucleus.*—This is accomplished by a succession of events corresponding to those described as characterizing the phase during which the nucleus prepares for division, except that they occur in the reverse order—*i.e.*, the chromosomes abandon their star-like formation, adjust themselves to form a spirem, become mixed with the linin filaments, and lose their distinctness until the usual nuclear appearances are resumed.

This general outline of the cell division is, however, subject to many modifications necessitated by the simplicity and complexity of the cells and the number into which they divide.

In those cells in which no nuclei can be discovered by existing methods of examination, no nuclear changes can be associated with division. The cell having grown

to a certain size, appears to separate into two or more equal parts, each of which takes on an independent existence. The structure of certain cells, as the bacteria, is still controversial. Some believe them to have large nuclei and see in them appearances analogous to those of karyokinesis at the time of division. It is usual, however, to describe the division of these organisms as taking place by direct division, *i.e.*, simple fission without karyokinesis.

FIG. 32.—Direct division of lymphocytes of a frog. (*Arnold.*)

Concerning certain nucleated cells of the metazoa we are also still in doubt. Thus, Arnold and others have described simple fission or direct division in certain lymphoid cells of man, but whether their observations would bear the test of more improved methods of examination is not yet determined. The more perfect the methods of staining and examining the cells, the more strongly we become convinced that there is no cell division independent of antecedent changes analogous to karyokinesis.

When the cell divides into many segments, the karyokinetic process is of necessity modified to conform to the requirements of the case. The primary division appears to take place in the centrosome. If two are formed, there

will be a simple nuclear spindle and the nuclear material being equally divided and drawn toward them, two new nuclei and two new cells will result; if there are four divisions of the centrosome, there will be two nuclear spindles and four new nuclei; if a greater number of divisions of the centrosome, a still more complex arrangement of spindles and a still greater number of nuclei will be formed. In the sporozoa in which great numbers of minute cells or spores arise through the division of one large one, the chromosome formation and nuclear spindles are theoretically present but not actually visible.

In morbid conditions the process of cell division may miscarry in a variety of ways. Thus, in the event of the separation of the nuclear material being imperfect and incomplete, a large lobulated nucleus may be formed; in case the nuclear divisions are completed without accompanying division of the cytoplasm, giant cells may be formed.

CHAPTER VII.

THE HIGHER ORGANISMS.

A superficial acquaintance with the structure of familiar living things is sufficient to enable a casual observer to arrrange them in a series in which they pass from the simple unicellular to more and more complex multicellular forms. This does not necessarily mean that it is possible to follow the individual steps through which the complexity was attained, nor does it imply ability to interpret the purpose of the many diverse forms to which this complexity has arrived. Such problems are reserved for consideration in a future chapter where it is hoped that they may be presented in a reasonable form.

It is difficult to avoid the conviction that complexity of structure, with the many differentiations and adaptations it embraces, is of great importance to living substance in improving the conditions of life and better adapting it to the exigencies of existence, yet simply and complexly organized forms of life exist in nature side by side, both equally able to persist. The idea of purpose in progress is, therefore, compelled to give place to the opinion that what is seen in this evolution is but evidence of the fact that life is cyclical and subject to changes by which modification is inevitable. The inutility of complexity is further exemplified by the fact that many highly complex and differentiated organisms have become extinct, while many simple organisms have persisted.

With increasing complexity of structure come more complicated conditions of life which make it more and

more difficult for the highly evolved organism to survive in the general struggle for existence.

The foreshadowing of organs—elementary organs—are to be found among the protozoa and indicate that these lowly organisms are subject to perhaps as much specialization as is compatible with their unicellular simplicity.

Thus from the protamœba and amœba whose shapes can scarcely be regarded as fixed, and which consist of plastic masses of protoplasmic jelly, we pass to higher amœba that cover themselves with more or less elaborate

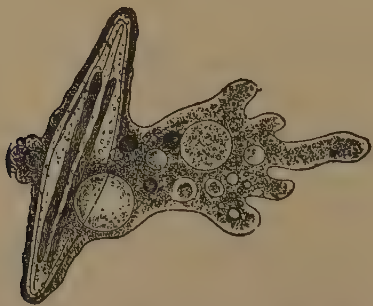

FIG. 33.—Amœba proteus (magnified). The largest sphere is the *contractile vacuole;* the smaller is the *nucleus.* A large diatom is seen on the left, and numerous paraplasmic granules are scattered through the protoplasm. (*Masterman.*)

cases composed of minute particles of mineral substance, and then to the foraminifera in which the body substance is surrounded by fantastic calcareous shells through fixed openings in which the pseudopods may be protruded. We next pass to other forms in which the development of the cell wall occurs as a hyaline but rigid cuticle giving permanent form to the organism as in Paramœcium, Vorticella, Epistylus, Stentor, etc.

In the flagellates and ciliates we find the cuticular cell wall perforated by many minute openings through which special rigid protoplasmic threads project for

purposes of motion and locomotion. Many of these forms are further provided with fixed oral openings surrounded by cilia directing currents into a tubular aperture terminating abruptly in the cytoplasm, but acting as a primitive alimentary canal.

Likewise we find the desmids and diatoms among the vegetable cells provided with complex cellulose envelopes and silicious skeletons, and foraminifera and radi-

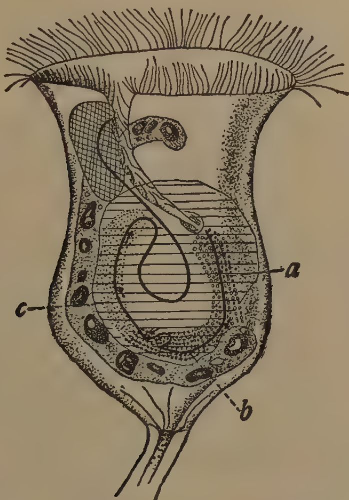

FIG. 34.—*Carchesium.* Showing beginning specialization. (*Greenwood.*) The path which the food takes is represented by dots. *a* (circular round marks) represents the position of storage; *b* (crosses) represents the position of rest; *c* (dots), the region of the later changes.

olaria among animals with wonderfully elaborate silicious skeletons which endow the organism with definite form and increase its rigidity.

These primitive specializations find their homologues in the dermal coverings, the limbs and fins, etc., of the higher animals.

It is self-evident, however, that an organism composed of a single cell is less well able to increase its complexity

than one composed of many cells, groups of which can be set aside for special purposes.

Composite structure, however, does not necessarily imply complicated structure; it only affords opportunity

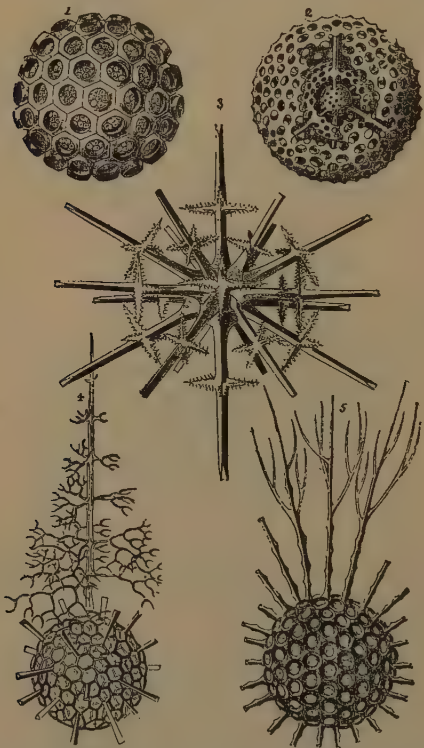

FIG. 35.—Various forms of Radiolaria. (*After Haeckel.*)
1, Ethmosphœra siphomophora; 2, Actinomma inerme; 3, Acanthometra xiphicantha; 4, Arachnosphœra oligacantha; 5, Cladococcus viminalis.

for it. Thus we find lowly forms of life sometimes made up of congeries of similar cells whose cytoplasm has become united into a general undifferentiated mass or *plasmodium*. Such formations occur in both the animal

and vegetable kingdoms, but in neither do such plasmodia show the least tendency to differentiation of cells into *tissues* such as compose the more complex organisms.

The size of the organism bears very little relation to its complexity. It is true that size affords opportunity for differentiation, but some of the undifferentiated plasmodia are large enough to be measured in centimetres, while some highly differentiated and exceedingly complex organisms like rotifers are visible only through the microscope.

In endeavoring to ascend from the simple to the com-

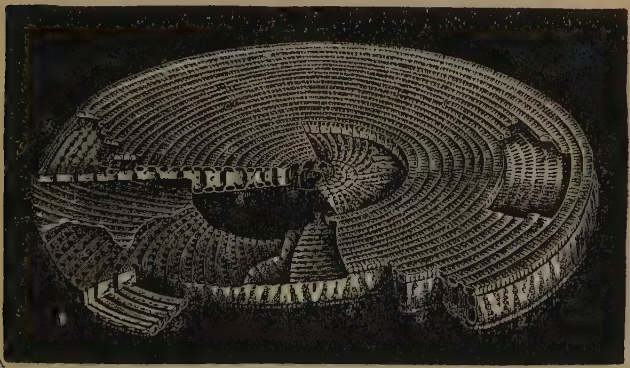

FIG. 36.—Orbitolites. Ideal representation of a disc of complex type. (*Carpenter.*)

plex we are confronted by certain conditions the full force of which cannot be felt until the chapter upon Divergence has been perused. One of the most important of these is the extinction of many of the intermediate forms, so that just when we seem to be comfortably started upon a series of easy anatomical gradations, we are obliged to skip a number of steps and endeavor to fill them with imaginary forms. Another and even greater difficulty is found in the fact that the process of differentiation is not uniform, specialization in certain

directions enabling us to create a fairly continuous series in that particular line, though the members of the series find no correspondence in other lines.

This discrepancy sometimes embarrasses systematic writers as they endeavor to perfect the classification of living things, for a classification based upon the resemblances of adult organisms might differ widely from one based upon embryological resemblances.

FIG. 37.—Fossil Diatomaceæ, etc., from Oran. *a, a, a,* Coscinodiscus; *b, b, b,* Actinocyclus; *c,* Dictyochya fibula; *d,* Lithasteriscus radiatus; *e,* Spongolithis acicularis; *f, f,* Grammatophora parallela (side view); *g, g,* Grammatophora angulosa (front view). (*Carpenter.*)

In the discussion before us greater success will probably accrue if the living things are compared without fixed ideas as to their precise position in the zoological or botanical classifications.

From the plasmodium in which association of many cells is followed by obliteration of the identity of each, and in which it is difficult to see that the association subserves any useful purpose or predisposes to the occurrence of complexity through increase of size or

number of individuals, we next pass into congeries of cells in which the identity of each is preserved, though no apparent utility is subserved thereby. This is seen, for example, in Spirogyra, where hundreds of organisms may adhere to one another, in Epistylus, Carchesium,

FIG. 38.—Microgromia socialis. A, Colony of individuals in extended state, some of them undergoing transverse fission; B, colony of individuals (some of them separated from the principal mass) in compact state; C, D, formation and escape of swarm-spore, seen free at E. (*Carpenter.*)

and other infusoria where organisms resulting from the division of the parent cell remain attached by their pedicles to a common stalk. A less fixed colonial aggregation is seen in Microgromia socialis, where individuals remain united for a time by their pseudopods, sometimes

more or less distant from one another, and connected only by delicate protoplasmic filaments, sometimes forming compact masses. Any individual seems able to withdraw from the union to found a new colony, though this is usually observed to follow division of one of the members whose descendant, assuming a modified form, escapes from the cell capsule in which it was born and deserts the colony.

In many cases the primary purpose of cell association appears to be founded upon reproductive advantages

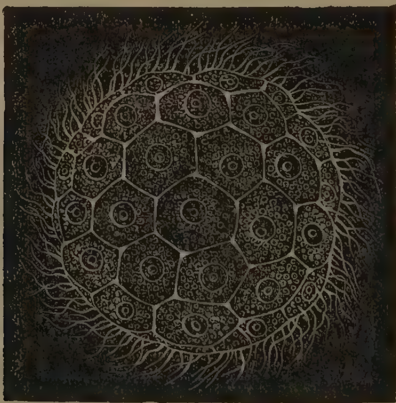

Fig. 39.—Magosphæra planula, a ciliated colonial protozoan. (*After Haeckel.*)

thus afforded, for one of the first structural specializations to be observed among the lowly forms of life consists of special reproductive cells.

We find that with the exception of the most lowly organisms of both animal and vegetable forms, reproduction takes place either exclusively or most advantageously when the newly formed individual or individuals receive substance directly or indirectly from two individuals of its kind (*amphimixis*). Emphasis will be laid upon the importance and significance of this in the chapter upon Reproduction.

So soon as it becomes clear that the purpose of cell association is reproduction, and so soon as it can be determined that among the associated cells some are

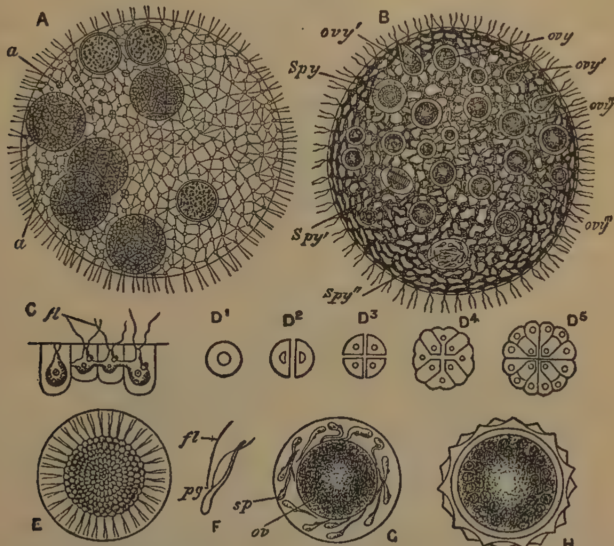

FIG. 40.—*Volvox globator.* A, the entire colony, surface view, showing the biflagellate zooids and several daughter-colonies swimming freely in the interior; the latter are produced by the repeated fission of non-flagellate reproductive zooids (*a*). *B*, the same during sexual maturity, showing spermaries from the surface (*spy*), in profile (*spy'*) and after complete formation of sperms (*spy''*); and ovaries from the surface (*ovy*, *ovy''*, *ovy'''*,) and in profile (*ovy'*). C, four zooids in optical section, showing cell wall, nucleus, contractile vacuole, with adjacent pigment-spot, and flagella (*fl*). D^1–D^5, stages in the formation of a colony by the repeated binary fission of an asexual reproductive zooid. E, a ripe spermary. F, a single sperm, showing pigment-spot (*pg*) and flagella (*fl*). G, an ovary containing a single ovum surrounded by several sperms. H, oosperm enclosed in its spinose cell wall. (*After Kirchner; B–H after Cohn.*)

destined to perform the reproductive function alone, the advantage of the association becomes clear for the reproductive cells may then be relieved of other functions through the vicarious activity of the other cells.

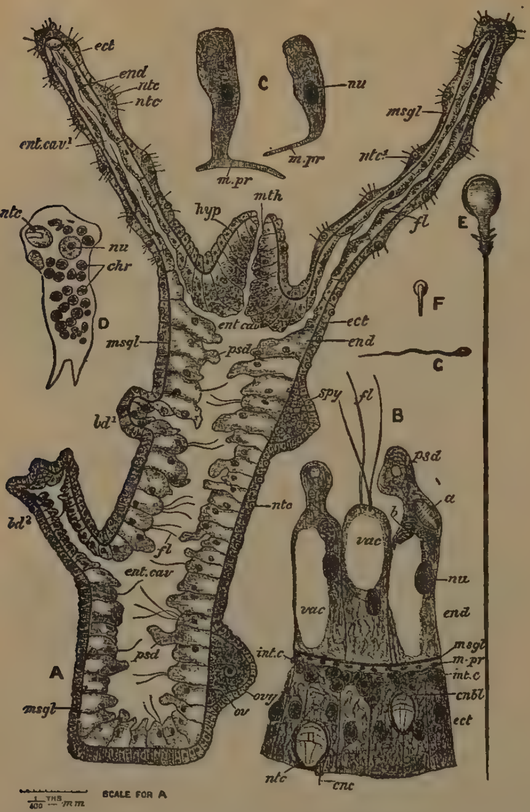

FIG. 41.—Hydra. A, Vertical section of the entire animal, showing the body wall composed of ectoderm (*ect*) and endoderm (*end*), enclosing an enteric cavity (*ent. cav*), which, as well as the two layers, is continued (*ent. cav'*) into the tentacles, and opens externally by the mouth (*mth*) at the apex of the hypostome (*hyp*). Between the ectoderm and endoderm is the mesoglœa (*msgl*), represented by a black line. In the ectoderm are seen large (*ntc*) and small (*ntc'*) nematocysts; some of the endoderm cells are putting out pseudopods (*psd*), others flagella (*fl*). Two buds (bd^1, bd^2) in different stages of development are shown on the left side, and on the right a spermary (*spy*) and an ovary (*ovy*) containing a single ovum (*ov*). B, portion of a transverse section more highly magnified, showing the large ectoderm cells (*ect*) and interstitial cells (*int. c*); two cnidoblasts (*cnbl*) enclosing nematocysts (*ntc*), and one of them produced into a cnidocil (*cnc*); the layer of muscle processes (*m.pr*) cut across just external to the mesoglœa (*msgl*); endoderm cells (*end*) with large vacuoles and nuclei

A beautiful example of this is shown in the case of Volvox globator. This little plant begins its life history as a hollow sphere composed of cells which at first show no essential differences, are somewhat polyhedral in form, and separated from one another by a hyaline material. About the whole mass there is a distinct membranous formation. Among the component cells one larger than the others can early be distinguished. As the total number of cells continues to increase and the hyaline intercellular substance likewise to increase, this particular cell enlarges and then divides by successive segmentations until as many as sixty-four or even one hundred and twenty-eight similar cells have been formed. These are the reproductive cells. As their fertilization is perfected, they project into the central cavity of the hollow organism, eventually divide into many cells, of which a similar hollow sphere is formed which remains in the body of the parent until upon its dissolution a number of young spheres are simultaneously set free to repeat the cycle described.

We have no right to regard anything that takes place in nature as accidental simply because we see no purpose in it or reason for it. We must not, therefore, hastily conclude that loose combinations of organisms, such as we see in Streptococcus, Spirogyra, Epistylus, Carchesium, Microgromia, etc., are unimportant to the organisms concerned.

By having many cells a division into somatic and germinal forms is quickly followed by the development of the former as the hosts or caretakers of the latter. Such a primary differentiation is in turn soon followed

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(*nu*), pseudopods (*psd*). and flagella (*fl*). The endoderm cell to the right has ingested a diatom (*a*), and all enclose minute black granules. C, two of the large ectoderm cells, showing nucleus (*nu*) and muscle process (*m. pr*). D, an endoderm cell of H. viridis, showing nucleus (*nu*), numerous chromatophores (*chr*), and an ingested nematocyst (*ntc*). E, one of the larger nematocysts with extruded thread barbed at the base. F, one of the smaller nemotocysts. G, a single sperm. (*A, B, C, E after Parker, "Lessons in Elementary Biology"; D after Lankester; F and G after Howes.*)

by the development of the soma or body cells into groups set aside for special functions, such groups becoming more and more differentiated by the continually increasing complexity. The movement once started advances rapidly after the void between the unspecialized unicellular and the definitely specialized multicellular forms of life has once been bridged.

With the increasing complexity of the soma come differentiations which seem to affect it alone, but react upon the germ. Thus, for example, one might doubt that the possession of ornamental appendages could in any way benefit the germ, but analysis of the question will show that it is one of the circumstances by which the good of the host is advanced and so is of importance to the germ. Indeed the evolution of living matter depends in large measure upon the reciprocal relationships of the soma, and the germ.

Continuing to study increasing complexity, we pass from those examples in which the combination of cells appeared to be temporary and loose, any detached member of the colony being able to maintain itself and eventually to establish a new colony, as in Microgromia, Carchesium, and Epistylus, to such as Volvox where the combinations are fixed and permanent and individual members detached from the whole languish and die.

Among the metazoa we find no fixed combinations of undifferentiated cells forming single organisms. In the very lowest we find definite disposition of the cells—a regular arrangement—to subserve a definite function. Thus among the sponges and the hydras we find the cells disposed in two chief layers whose functions differ more than their general appearance. The fresh-water hydra consists of two layers of cells, an outer forming the ectoderm or covering layer and an inner forming the entoderm which is digestive and nutritive. The entire animal, its body as well as its tentacles, and any budding offspring that may be attached to it, is composed of these two simple layers. Between them is a narrow in-

terval usually without cells, but sometimes containing cells of amœboid character that have crawled in between the other cells. This space with whatever cells it contains is called the mesenchyme. In such a simple organism, the chief office of the outer cells of the body is to protect it by forming an elementary or primitive cuticle. The office of the cells of the inner layer is to dissolve nutri-

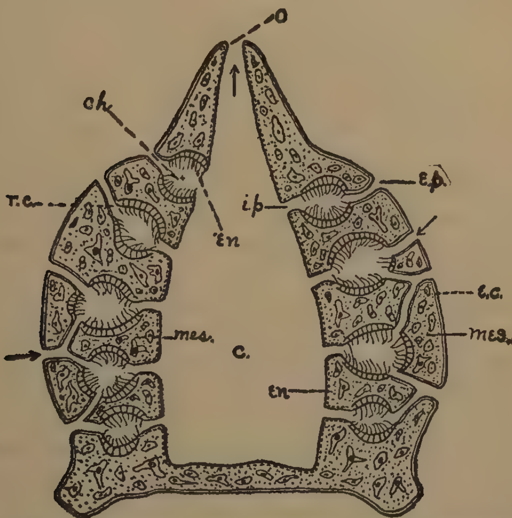


FIG. 42.—Diagram of simple type of sponge. *c*, cloaca; *ch*, chambers, lined with flagellate entoderm; *e.p*, external pores; *i.p*, internal pores; *mes*, mesenchyma; *o*, osculum; *r.c*, radiating canals; *ec*, ectoderm; *en*, entoderm. In the adult sponge the canals and flagellate chambers become much more complex than figured here. (*Galloway*.)

tious particles brought into the body cavity by the tentacles. Through their action the fluid contained in the body cavity becomes nutritious enough to enable the cells to live by absorbing it, the inner cells passing it to their next neighbors of the outer layer, or permitting it to transfuse into the mesenchyme from which it reaches them.

Among the porifera or sponges, as among the higher cœlenterates, the mesenchyme increases in importance so that we have three tissues, the ectoderm, the entoderm, and the mesenchyme, which may be regarded as the starting point of all the future differentiations for even among the highest animals, and in man himself, the tissues are still divided into those springing from one or the other of these three structures, the outer of which is the source of the integuments, the inner the source of the organs of digestion, and the middle the source of the organs of support and locomotion.

The increasing structural complexity appears to be largely a matter of necessity. As the number of cells increases, and specialization of these cells is gradually effected, it becomes inevitable that all should not be favorably situated with reference to the source of nutrition, so that some means must be provided for conveying suitable pabulum to them. As more of the nutritive pabulum is required, greater perfection of the organs of motion or prehension must be developed in order that it may be supplied, and greater perfection of the digestive organs becomes necessary that none of it wastes. As the differentiation of parts becomes more and more perfect, and their interdependence increases, means by which one part may communicate with another appears in the form of the nervous system.

Should we, however, seek to explain complexity of structure by conditions intrinsic in the organism itself, and solely along the lines suggested in the preceding paragraphs, we must inevitably fail. Such conditions would determine a uniform evolution of the developing substance and not result in the diversity of structure found among the many phyla of plants and animals. The chief sources of structural modification lie outside of the organism in its environment as will be explained in a subsequent chapter.

We will now endeavor to trace each of the important systems of organs back to its inception, remembering

that in most cases their homologues can be found in exceedingly elementary forms of life.

The Reproductive System.—It has already been suggested that reproduction is at the very foundation of cell association, and therefore is one of the first, if not the first, specialization of the composite organism. At first it is so indefinite that any cell may apparently take on the function when the appropriate moment is at hand and the germinal cells seem to be widely scattered among the somatic cells, but gradually they become collected into groups—gonads—which form the foundation of the reproductive organs. A future chapter will be devoted to the subject of reproduction.

The Digestive System.—Unicellular organisms nourish themselves as they perform all other functions, through activities of their own. Nutritious materials absorbed or ingested into their substance meet solution by digestion and subsequent assimilation in the cell, the residuum being extruded. Among the colonial protozoa the cells may or may not retain this independence. Thus in epistylus and carchesium, we have no reason to suppose that any individual contributes to the support of any other. In microgromia, however, it may be that cells that are more successful in gathering up nutritious matter give up some of the proceeds to the less successful cells through their protoplasmic connections. Among vegetable cells community of interest in regard to nutrition appears very early and assumes great importance for what is seen among the most lowly forms of animal life, *i.e.*, the transmission of nutritious pabulum from cell to cell persists even among the higher forms of vegetable life.

Among the elementary animal composits the differentiation of function is not sufficient to prevent almost any cell yielding to primitive tendencies. Thus among the porifera the digestive cells constantly, and in hydra not infrequently, take useful particles directly into their own substance. This is particularly interesting in

hydra where a well-formed digestive cavity is present. Large objects entering the oral orifice are dissolved in the gastric cavity by enzymes derived from the entodermal cells, and the assimilable products of this digestion are absorbed. Small particles are liable to be seized upon by the cells and treated by the more primitive process of phagocytosis or intracellular digestion. The more complex cœlenterates continue to display more or less of this phagocytosis of the entodermal cells, but as we ascend into the phylum Annulata the specialization of the entodermal cells as digestive enzyme producers becomes so distinct that it disappears not to be seen again among the higher animals.

The primitive digestive system exemplified by the gastric cavity of hydra, in which the oral orifice subserves the double purpose of mouth and anus, finds an improvement in the echinoderms and worms by the addition of a separate anus at its aboral end. The food ingested now passes slowly through the *enteron* as Haeckel has called this primitive stomach-intestine, being digested, during its passage, the residuum being discharged from the anus. The further specializations are for the most part in the improvement and localization of the digestive forces. The enteron becomes more and more tubular and gradually separates itself into a mouth for mastication, which is provided with a variety of different appendages, teeth for crushing and comminuting, salivary glands for moistening the food, etc., a gullet through, which the food enters the main digestive viscus, a stomach, and an elongated intestine from which absorption of the products of digestion may take place.

Instead of the digestion being partly intracellular, the cells are specialized as enzyme producers, arranged in glands by which digestive juices are poured into the alimentary canal and mixed with the food so that combined maceration, solution, and digestion may prepare the assimilable substances for absorption from the intestine.

Gradually the glandular organs are perfected and separate enzymes for acting upon proteins, fats and carbohydrates provided.

Thus the digestive function ceases to be a cellular function though it continues to be the result of the combined activity of many variously specialized cells.

The digestive organs also gradually come to stand in close relation with the organs of excretion so that offensive digestive products may be removed from the blood before it is distributed to the general system. For this purpose the liver is interposed between the digestive organs and the systemic circulation.

Vegetables that nourish themselves upon comparatively simple inorganic compounds diffused through the air and water need no organs of digestion while to animals that nourish themselves upon highly complex vegetable and animal proteins they are indispensable.

The digestive apparatus thus becomes a factor of much importance in animal morphology and development. Except among the protozoa and a few parasitic worms its presence is invariable. It must be proportioned to the requirements of the animal, but just as the animal cannot live without it, it cannot be of use unless means are furnished for providing it with material to work upon. Such material is usually acquired through movements effected by special organs.

The Motor System.—Here we have to consider those organs whose primary purpose seems to be to enable the organism to secure its food. The vegetable world is with few exceptions without organs of prehension, motion, or locomotion because they are not needed. Moisture sucked from the soil by roots, and gases and moisture taken from the air by leaves constitute the materials upon which the vegetable world subsists, and as these are always available no special organs are required to obtain them.

Animal organisms, however, must have food in the form of highly combined products, only to be derived

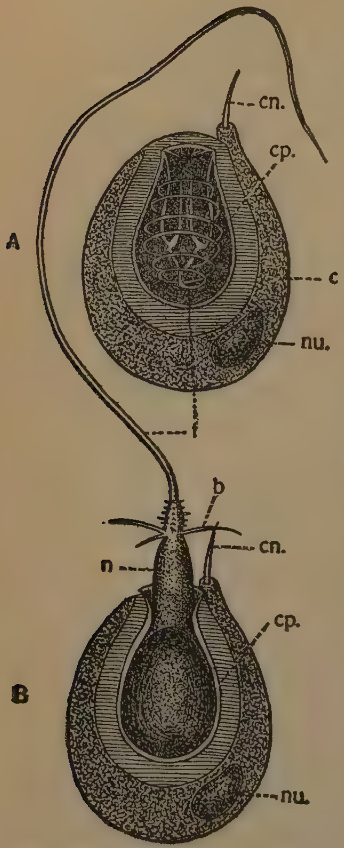


FIG. 43.—Nettling cells of Hydra. (*After Schmeil.*)

A, Unexploded; B, exploded. *b*, Barbs; *c*, the nettling cell in which the nettling organ is developed; *cn*, the cnidocil or "trigger"; *cp*, the capsule or nettling organ; *f*, the nettling filament or lasso; *n*, neck of the capsule; *nu*, nucleus of the cell.

from antecedent forms of life, and as these are not to be found everywhere, either the animal must wait until such come to it and then seize them, or go in search of them. Thus comes about the necessity which is met by the development of organs of *motion, locomotion,* and *prehension.*

The unicellular organisms show the most primitive of these in the pseudopods of the amœba, and the cilia and flagella of the infusoria. Pseudopodia subserve all three purposes, motion, locomotion, and prehension, but cilia and flagella are higher specializations and confine their usefulness to motion, by which stationary cells produce currents in the surrounding fluids, and locomotion by which the cell is propelled through the fluid in which it lives.

Further specializations also occur in regard to the cilia, certain of them being adapted to locomotion, and certain arranged in such manner as to direct currents of fluid toward the oral orifice of the organism.

The elementary composits composed of fairly homogeneous elements possess no special motor organs. Their cells may be amœboid as in microgromia, or they may be ciliated as in volvox, the cilia being so disposed as to serve the best interests of the colony. In volvox they are placed externally to permit movement; in the porifera, which are immobile, the ciliated cells are internally disposed so that their lashing produces currents of water which constantly flow through the radiating canals carrying in the minute particles upon which the amœboid cells of the entoderm seize.

True prehensile organs, composed of many cells, first make their appearance among the cœlenterates, and are most simple in hydra, where they form a circle of from six to ten long slender arms about the oral aperture. Each of these arms or *tentacles* has a structure corresponding with the body of the animal itself, that is, it consists

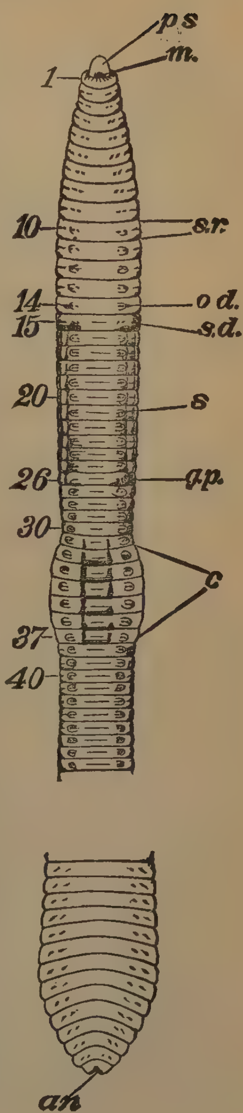


Fig. 44.—Enlarged view of the anterior and posterior parts of the body of an earthworm as seen from the ventral aspect. *an*, Anus; *c*, clitellum; *g.p.*, glandular prominences on the twenty-sixth somite; *m*, mouth; *o.d*, external openings of the oviducts; *p.s*, prostomium; *s*, setæ; *s.r*, openings of the seminal receptacles; *s.d*, external openings of the sperm ducts. The form of the body varies greatly in life according to the state of expansion. The specimen here shown is from an alcoholic preparation (slightly enlarged). (*Sedgwick and Wilson.*)

of ectodermal and entodermal cellular layers, and is hollow, the space communicating with the general body cavity. The ectodermal cells of the tentacles, however, present a peculiar specialization not seen in other parts of the ectoderm, namely, the possession of certain "nettling cells," which are intended to aid in securing the microscopic organisms, upon which the animal preys, by stinging or stunning them in order that they may be better grasped and introduced into the body cavity. Each of these nettling cells contains a beautiful mechanism consisting of a capsule in which a long stinging filament is closely coiled. A second small filament, trigger or *cindocil*, projects from the cytoplasm. When the trigger contacts with a suitable object, the trap springs and the filament is suddenly thrown out against it with stinging and paralyzing effect. In addition to the nettling cells the ectoderm seems to contain certain primitive muscle cells which increase the mobility of the tentacles.

Though the tentacles are primarily organs of prehension they also serve as organs of locomotion; for, should a change of position be advantageous, the hydra bends over, seizes an object with its tentacles, lets go its foothold, gradually turns over and effects a new attachment elsewhere.

Leaving the hydroids and passing to the higher cœlenterates a functional differentiation soon separates prehension, which is limited to the tentacles, from locomotion which is effected by the development of muscle cells in the umbrella as in medusa where the alternate contraction and expansion enables the animals to swim about.

Distinct locomotory appendages appear in the segmented worms in the form of bristles or setæ attached to each segment and directed backward. As the muscular movements force the body of the animal forward these appendages catch upon irregularities of the surface upon which it moves, and prevent retrogression of the ad-

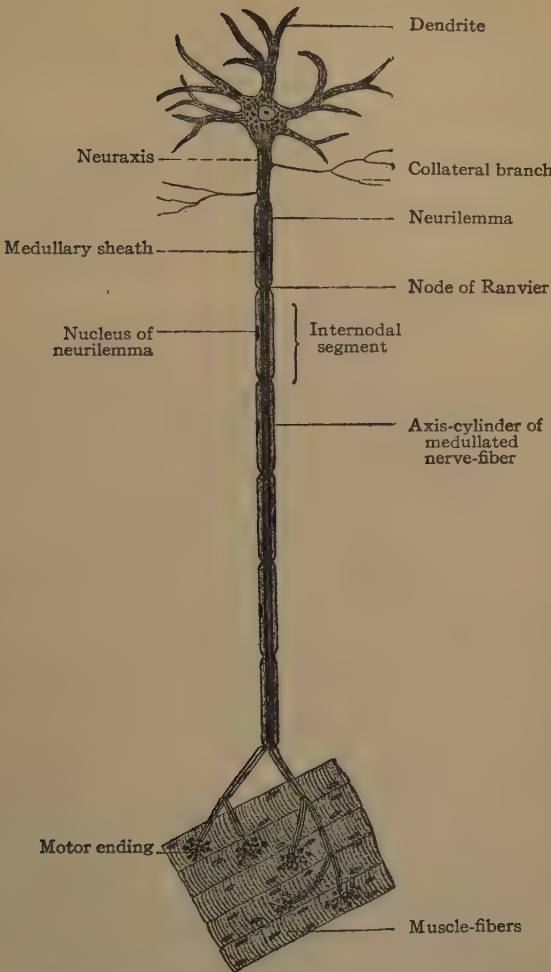


Fig. 45.—Diagram of peripheral motor neurone, showing the specialized contractile tissue, the muscle, the specialized conducting tissue, the nerve fibre, with the motor endings in the muscle, and the source of the stiumlation, the nerve cell. (*Böhm, Davidoff and Huber.*)

vanced segments as the remainder are drawn after them.

Among the arthropods the function of locomotion becomes highly specialized by the development of jointed appendages controlled by muscles attached to all or certain of the segments.

Among the vertebrates the same general plan of having the motor organs spring from certain of the body segments is preserved, though they undergo great modification in their specialization into fins, wings, legs, arms, flippers, etc., with complicated muscular and other adjustments.

Frequent allusion has been made to muscle cells and muscles so that it becomes necessary to say a few words about these as important adjuncts to the motor apparatus.

In the tentacles of certain hydras, in the higher cœlenterates, and in all of the higher animals there are certain mesenchymal cells that specialize in contractility. These are known as *muscle cells.* They are of elongate shape, but are capable of manifesting their contractile power by shortening and thus making traction upon the structures to which they are attached. Primarily of this spindle shape and appearing singly, they are associated in groups and bundles in the higher animals where their combined action is very effective as sources of movement. Eventually they appear as elongate multinucleated, transversely striated fibrils, singly or in bundles—the voluntary muscles—which are the source of the extensive and powerful movements of the higher animals.

The Circulatory System.—So soon as cell combinations become so large or so differentiated as to make it impossible for each cell to exist under conditions common to all the cells, it becomes desirable that some special means be provided by which the less advantageously situated cells may be provided with nourishment and have their effete products removed.

In the most simple cell colonies, such as Microgromia, Carchesium, Epistylus, and Volvox, the cells, though

connected, are too independent to feel this need; but in the sponges and hydras the differentiation of the cells becomes sufficient to give the entodermal cells an advantage over others unless some means for transporting the products of digestion can be found. In all probability the primitive means is similar to that seen among plants where material of various kinds is passed directly from cell to cell. Such primitive methods cannot suffice, however, except in cases in which the cell groups are small.

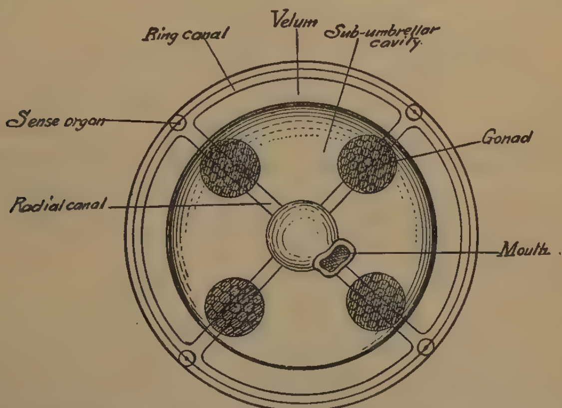


Fig. 46.—A medusa of Obelia. Seen from the oral surface, magnified (*ad nat.*) (*After Masterman.*)

Plants soon outgrow the direct transfer and provide themselves with "vascular tubules" through which the sap flows in a continuous current from the roots to supply the evaporation in the leaves.

The lower cœlenterates among animals, by contracting the body, force its contained fluid rich in nourishment into every part including the hollow tentacles.

Ascending a little higher among the hydroids we find some of them—Coryne, Obelia—giving off budding offspring minute in size but resembling a medusa or jelly fish in shape. From the centre of each of these embryos

there hangs down a hollow open sac called the *manubrium*. This is in reality its stomach, but it opens into several canals that radiate from the centre and communicate with another canal that courses along the margin of the disc. This slightly more complex arrangement is known as the *water vascular system*. It begins in the stomach and from it carries the contents—water with products of digestion—through the tubes and back again, thus affording cells remote from the actual organ of digestion an opportunity to effect an exchange of useful for useless matter.

As we ascend to the true jelly fishes we find the same

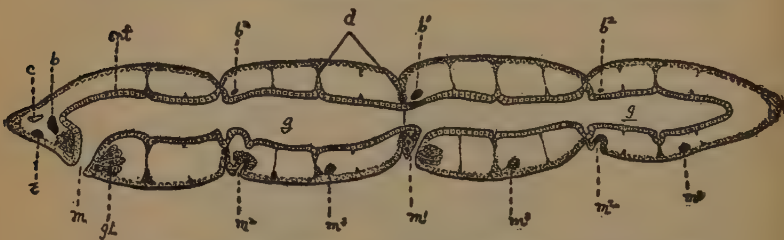


FIG. 47.—Diagrammatic sagittal section of *Microstomum*, showing a chain of four zoöids produced by fission. *b*, Brain of the original zoöid (the exponents indicating corresponding structures of the more recently formed zoöids); *c*, ciliated pit; *d*, dissepiments indicating different stages in the separation of the zoöids; *e*, eyespot; *ent*, entoderm: *g*, gut; *gl*, glandular cells about the mouth; *m*, mouth of the original worm. (*Galloway*.)

arrangement, the only difference being in the number of radiating tubes and an increasing complexity of anastomosing branches by which the circulating fluids are permitted to come in contact with a greater number of cells. The propulsive force is found solely in the muscular movements made by the swimming animal as it opens and closes its transparent umbrella.

Among the unsegmented worms the device for distributing nourishment does not differ fundamentally from what has already been described. It consists of a water vascular system comprising two main lateral tubes with many branches extending to the periphery

of the body. A new specialization makes its appearance, however, for at least a part of the fluid thus distributed does not return again to the stomach-intestine, but leaves the body through pores guarded by special cells. Here in intimate relation to the primitive circulatory apparatus we find the inception of the essential function of excretion or the elimination of effete matter.

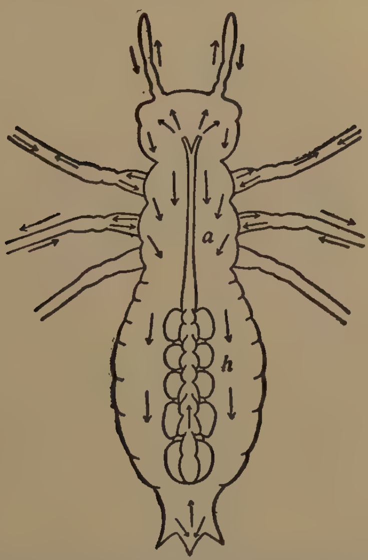


Fig. 48.—Diagram to indicate the course of the blood in the nymph of a dragon fly. *Epitheca.* *a*, Aorta; *h*, heart; the arrows show directions taken by currents of blood. (*After Kolbe.*)

The crudity of a system that permits the entire contents of the alimentary canal to enter the circulating pabulum is superseded by complete separation of the digestive and circulatory systems; with corresponding improvement in the quality of the systems thus separated, the blood can no longer be propelled by movements of the alimentary apparatus and for its proper circulation it becomes essential that the great vessels

be contractile, a specialization readily observed among the lower worms and laying the foundation of the organ known as the heart.

The larger vessels are at first in intimate relation with the alimentary tract which they surround with loops. Muscular fibres are present in these large vessels so that as the products of digestion are absorbed into the blood, a slow rhythmical contraction propels the blood in a circuit of the tissues. At first the arrangements are so primitive that the course of the blood is uncertain, but as the specialization becomes improved there is an increasing tendency for the flow to maintain a constant direction, efferent and afferent vessels being differentiated and a primitive separation of arteries and veins thus established. In the elementary form in which this condition is observed there are no capillary vessels connecting the two so that the circulation is not closed. True capillaries first appear among certain of the worms, though many higher animals—as, for example, insects—are without them. In the higher annulates and among the arthropods the major vessel becomes expanded into a primitive heart which receives the blood from several large veins whose orifices are provided with valves preventing backward flow so that the stability of the circulation is established. The muscular movements of the heart now become rhythmical, regular, and slow. Such simple hearts are found among the arthropoda generally.

The greater number of the animals thus far used as examples of the increasing complexity of the circulatory system are aquatic and of small size as well as comparatively simple in structure. As they increase in complexity by the differentiation of systems of organs, as they increase in size, and as they acquire a terrestrial mode of life, a new requirement is presented which necessitates the development of a new system of organs as well as a further increase in the complexity of the circulatory apparatus. This is the need of oxygen. The relatively simple organisms acquire this from the fluids in

which they live, at first by surface absorption, then when differentiated into an outer derm and an inner gastric cavity, partly by absorption from the external surface and partly through the gastric contents, then by the transmission of the constantly changing gastric contents, through the gastro-vascular system. When the blood becomes a permanently differentiated fluid enclosed in vessels, some oxygenation is effected through the surface of the body as the blood is slowly moved about by the primitive heart, but as the complexity of the organisms increases and large groups of cells are set aside for various definite purposes, the supply of oxygen thus secured becomes inadequate for the support of the tissues and it becomes necessary that special oxygen-absorbing organs be provided and that the blood be regularly brought to them. This necessitates an improvement in the blood itself by which oxygen absorption may be increased, and an improvement in the means of circulating it in order that the freshly oxygenated blood may not be free to mix with that whose oxygen has already been exhausted—that is, a separation of arterial and venous blood.

As has been shown, the pabulum supplied to the cells of the most lowly forms of life differs from the surrounding fluid in which the animal lives only in containing an increased quantity of nutritious material available for absorption or direct incorporation by the cells, this condition persisting until the separation of the vascular system from the digestive system is complete. The nutrient pabulum then first deserves the name *blood.* It continues for some time to be an aqueous fluid. Occasionally one finds a few amœboid cells from the mesenchyme circulating in it and picking up any solid particles that may accidentally enter. As the scale of life is ascended the number of these increases and their occurrence becomes more regular until in molluscs and arthropods these amœboid "*white corpuscles*" are constant elements of the blood. The blood, in the mean-

time, becomes more concentrated and as its specific gravity increases its oxygen-absorbing capacity is also increased.

With the appearance of true respiratory organs—gills in the crustacea—the circulation becomes modified in a simple fashion. The primitive heart discharges the blood into several large vessels one of which conveys it principally to the gills, where it is aerated as will be shown later, from which it returns to the heart to become mixed with the blood returning through other afferent vessels, imparting its oxygen to the whole with which it mixes before being sent upon a new circuit. The aerating circuit is not definitely separated from that of the tissues in the neighborhood of the gills; a very small fraction of the total blood is carried to the gills and after being aerated it mixes with the general blood mass. The arrangement is very perfect when contrasted with that found in mammals, but answers the necessities of the animals in which it occurs.

Among some of the invertebrates the blood corpuscles are found to contain small quantities of a reddish substance known as *hemoglobin* which forms a loose combination with oxygen highly advantageous to the blood by increasing its oxygen-carrying power. Among the vertebrates, however, the blood corpuscles are always of two kinds, the whites or *leucocytes* which are amœboid and contain no hemoglobin, and the reds or *erythrocytes* which invariably contain it, the proportion of the latter increasing until among the highest mammals they exceed the leucocytes in the proportion of 1 white to 750 red. At first the corpuscles scarcely differ from one another except in containing hemoglobin, but eventually the erythrocytes become so differentiated that they appear only as minute discs or cups of hyaline stroma without nuclei and thoroughly impregnated with hemoglobin. This enables the blood to absorb and transport to the tissues immensely more oxygen than would otherwise be possible.

As the perfection of the oxygen absorbing and distributing quality of the blood thus improves, the means of circulating it also improves through more complex adjustments of the heart and vascular system by which freshly aerated blood is continually supplied to the tissues and organs and is prevented from mixing with the ex-

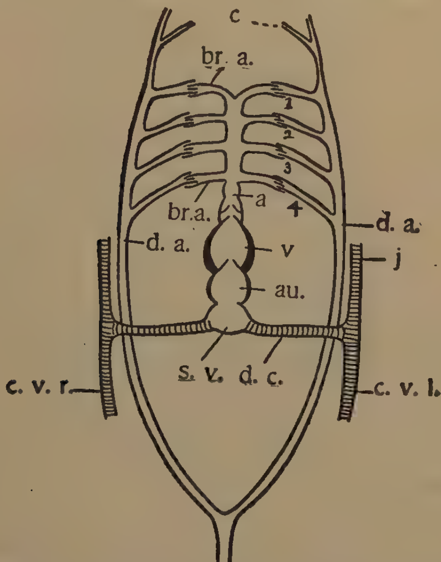


FIG. 49.—Diagram of the heart, the branchial arches, and the principal veins in the Teleosts. Ventral view. The heart is represented without the sigmoid flexure; that is, with the auricle posterior. *a*, Aorta; *au*, auricle; *br.a*, branchial arches of the aorta (1–4, numbering from the front); *c*, carotid; *c.v*, cardinal veins (right and left); *d.a*, dorsal arteries; *j*, jugular veins; *d.c*, ductus Cuvieri; *s.v.*, sinus venosus; *v*, ventricle. (*Galloway*.)

hausted blood returning from them. Thus there come to exist two distinct circulations: one for the aeration of the blood, the other for the nutrition of the organs and tissues.

The transformation in the structure of the heart by which this is made possible is not difficult to understand.

In the fishes the heart is tubular and consists of two chambers, a posterior auricle and an anterior ventricle. As in the crustacea, the blood is forced by the anteriorly situated ventricle into the aorta, which gives off large branchial arteries in pairs, itself dividing to form the anterior pair, passes through the branchial arteries to the gills where it is aerated, and is then collected, beyond the gills, into two dorsal arteries, by which it is distributed throughout the body of the fish. After passing through the capillaries, it is collected by two large cardinal veins, from which it is brought through two vessels—ducti cuvieri—into the sinus venosus, passed into the auricle, and then into the ventricle to renew the circuit.

It is interesting to find three genera of fishes, survivors of forms common in past geological periods, which occupy a position intermediate between fishes and batrachia in so far as their circulatory apparatus are concerned. Of these Ceratodus, the Australian "lung fish," is more like other fishes, while Protopterus and Lepidosiren, the African "mud fish," are more like the batrachians. All are peculiar in possessing lungs as well as gills, the former a single lung, the latter a pair of lungs, and in having their circulatory apparatus modified in consequence.

In Ceratodus there is one lung which is small and of far less value as an aerating organ than the gills. Indeed the quantity of blood that is carried to it is very small, and has already passed through the gills, so as not to require this supplementary aerating action except when the fish is prevented from using its gills, during periods of drought when the ponds dry up or the water they contain becomes thick and muddy, through evaporation, and charged with offensive substances and fermentative gases. It is then that the lung subserves a useful purpose by tiding the fish over what might be called a period of air famine, and permitting the blood to come into contact with just enough air to enable life to be maintained. This extremely primitive pulmonary develop-

ment is unconnected with important changes in the heart or great vessels.

In Protopterus and Lepidosiren, however, the fishes are not only provided with gills, but also with two lungs of considerably larger size and of greater importance.

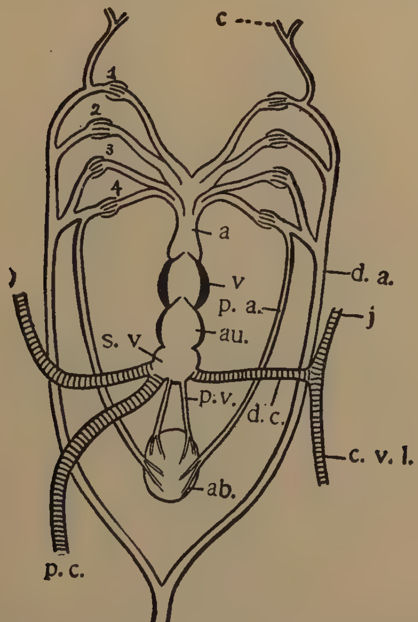


Fig. 50.—Diagram of the heart and branchial arches in Ceratodus (one of the Dipnoi). Position and lettering as in Fig. 164. *a.b*, air bladder (lung); *p.a*, pulmonary artery; *p.c*, post caval vein (right); *p.v*, pulmonary vein. (*Galloway.*)

In considering the changes necessitated through this improvement we must, however, bear in mind that the fishes by preference and under all favorable conditions, continue to live the life of fishes, remaining under water, and aerating their blood by means of gills and that it is only under exceptional circumstances that the use of

lungs is demanded. For this reason the gills continue to form the chief aerating organs, and the lungs an auxiliary mechanism to be held in reserve, hence the circulatory arrangements continue more closely to resemble those of gill-breathers than those of lung breathers. The bulk of the blood leaving the ventricle passes into an aorta,

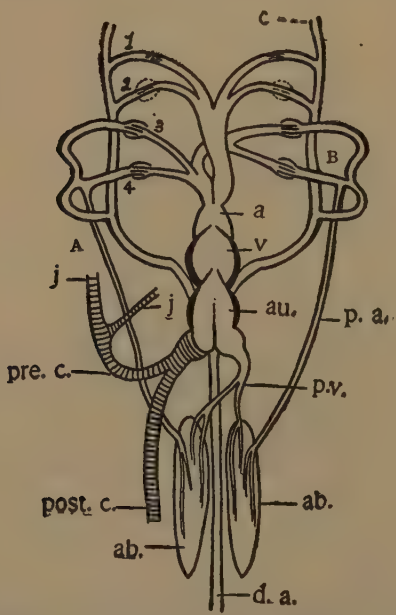


Fig. 51.—Diagram of the heart and branchial arches in Protopterus (one of the Dipnoi). Position and lettering as in the preceding. *pre.c*, precaval vein, made up of right and left jugulars, subclavians, etc.; *post.c*, postcaval, made up of the cardinals, right and left. (*Galloway.*)

then through the branchial arteries and is systemically distributed, while a small portion passes to the lungs, and then through pulmonary veins into the auricle. The only modification of the heart itself is a partial division of the auricle into two ill-defined chambers—right and left auricles. The right auricle which receives

the systemic blood is much the larger of the two. In both these lung-breathing fishes the blood undergoes a partial separation for that which goes to the lungs returns to the heart before it makes the systemic circuit. So that when the lungs are functional and the gills inactive the blood returning from the systemic circuit is in part

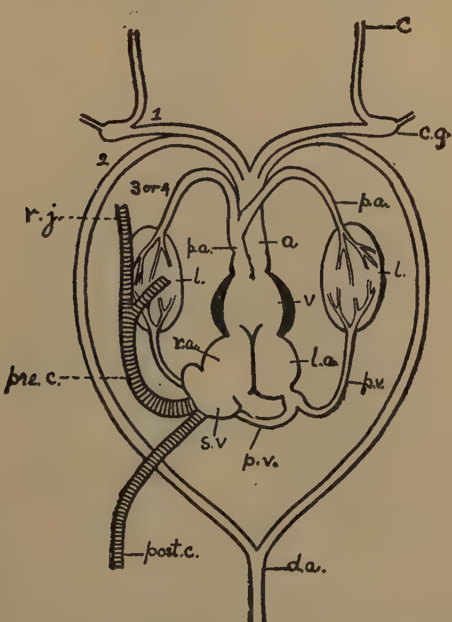


FIG. 52.—Diagram of the heart and branchial arches in the Frog. *c.g*, carotid gland; *l*, lungs; *l.a*, left auricle; *r.a*, right auricle. (*Galloway*.)

passed through the lungs before being again returned to the systemic circuit.

Among the batrachians the separation of the auricles becomes distinct. With a very few exceptions, these animals are gill-breathers in the larval stage, and lung breathers in adult life. This change necessitates a transformation of the vascular arrangements as the

aquatic is abandoned for the terrestrial mode of life. During embryonal life the circulation is carried on much as it is in the fishes, the branchial arches being conspicuous, but upon the attainment of adult life, and the establishment of a pulmonary circulation the bran-

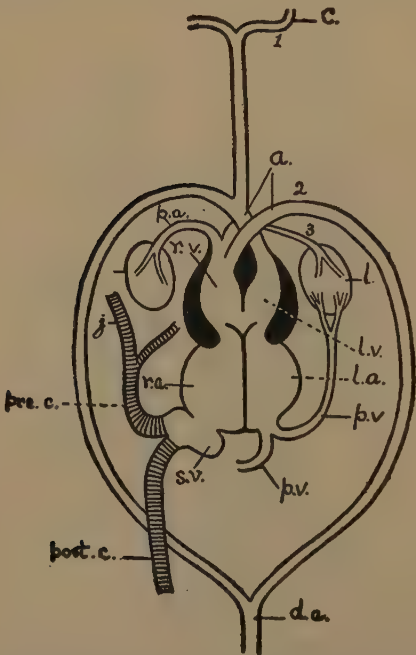


Fig. 53.—Diagram of the heart and branchial arches in a reptile. Position and lettering as in preceding figures. *l.v*, left ventricle; *r.v*, right ventricle (*Galloway*.)

chial arteries atrophy and true pulmonary circulation takes its place.

The frog affords an excellent example of the batrachian type of circulation. The heart is distinctly three-chambered, having one ventricle and two completely separated auricles. The blood discharged by the ventricle passes

to both systemic and pulmonary systems of vessels, that of the systemic circulation returning to the right auricle, that from the pulmonary to the left. Should both of these auricles discharge the blood into the ventricle without some provision for separating their contents,

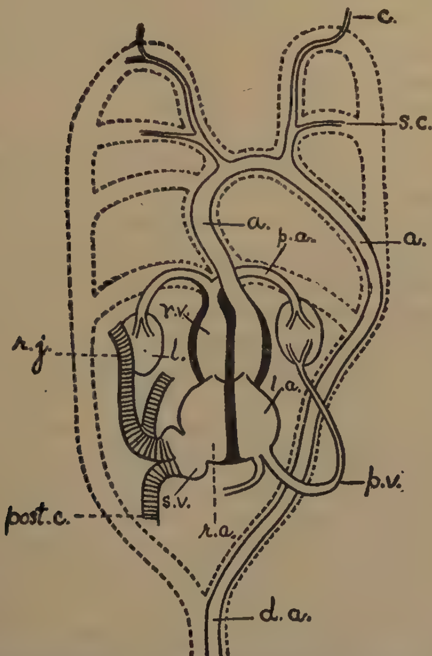


Fig. 54.—Diagram of the heart and the branchial arches in mammals. A dotted outline of the arches of the fish is drawn for ready comparison. The auricles are represented in a posterior position, as in the preceding figures. (*Galloway*.)

much of the advantage gained by the auricular separation would be lost. The substance of the ventricle is, however, peculiar in its sponginess, so that as the blood enters the freshly aerated portion from the left auricle is kept apart from the exhausted blood of the right ventricle, and when the ventricular contraction takes

place the blood is discharged in such manner that the freshly aerated portion rushes into the aorta and to the head and brain of the animal, while the exhausted blood later follows the greater part of it going to the lungs.

Similar primitive arrangements obtain among the batrachia, generally and also among the reptilia with the exception of the crocodiles. The reptilian heart is somewhat improved over that of the batrachia, but it is only in the crocodiles that the ventricle becomes completely divided by a septum.

In birds and mammals the circulatory system attains perfection in the sense that the heart is completely four-chambered and is thus able to effect a complete separation of the aerated or arterial from the exhausted or venous blood. In these animals the blood leaving the left ventricle is distributed by the aorta and its branches to the entire systemic circulation where it passes through the capillaries and is gathered together in two large veins, or *venæ cavæ*, which convey it into the right auricle. From the right auricle it passes into the right ventricle, and thence through the pulmonary artery to the lungs. Having passed through the pulmonary capillary plexuses for aeration, it is collected in several pulmonary veins by which it is returned to the left auricle, from which it passes into the left ventricle and again makes the systemic circuit. By these means a certain quantity of freshly aerated blood is constantly being distributed to the viscera for the support of their cells, while an equal quantity is always being sent to the lungs to be freshly aerated. The two circulations being independent of one another, no opportunity is ever afforded for the venous and arterial bloods to mix.

The Respiratory System.—Respiration being an indispensable function of living substance early requires special means by which it shall be made possible for all the cells of the composite animal to receive oxygen.

The unicellular organisms whose activities and requirements typify those of the cells of the higher composite

organisms absorb their supply of oxygen from the medium in which they live. This is, in fact, exactly what the cells of the higher organisms do, except that the medium in the first case is the water or atmosphere in which the cells live and in the latter the blood that is distributed to them.

Among the lower forms of life nutrition and oxygenation are intimately associated, and it is not until considerable complexity of structure is attained that it becomes necessary to provide special organs for the purpose of aerating the blood.

Thus, in the porifera or sponges, the ciliated cells of the entoderm, by causing currents of water to flow constantly through the various body pores, keep the cells of the animal constantly aerated. In hydra the cells of the ectoderm probably absorb oxygen from the water surrounding them, while those of the entoderm absorb it from the water in the body cavity. In the higher cœlenterates with a primitive vascular system, the circulating nutritious water distributed to the cells conveys sufficient oxygen to support such cells as may not be able to secure it from the surface of the body.

Among the unsegmented worms where the water vascular system is improved, respiration is still carried on partly through the surface of the body and partly by the primitive blood, but as the structural improvement confines the blood in vessels, or at least completely separates it from the contents of the digestive tube, some adaptation must be provided for supplying oxygen to the blood of the animal.

In their most simple form these consist of slight bulgings or projections of the surface corresponding with thin points in the dermal covering of the animal, at which the blood more easily takes up O and discharges its CO_2 than elsewhere. Such devices constitute the primitive *branchiæ* or *gills*, the first of the special organs of respiration.

As the scale of anatomical complexity is ascended the

size, number, distribution, structure, and arrangement of the branchiæ undergo great modification, but they continue to be the only means of effecting aeration of the blood so long as aquatic life continued. Modified branchiæ, indeed, persist among terrestrial mollusks.

In general arrangement the branchiæ consist of more or less well-protected, simple or complex surfaces upon which the blood of the animal is brought to the surface of the body, and in intimate contact with the surrounding water in order that the exchange of gases may be effected.

So soon as terrestrial life is adopted *lungs* are developed, and the atmosphere rich in oxygen is taken into the body and there aerates the blood. Lungs at first appear as relatively simple sacs into which air is drawn, and in the walls of which innumerable capillaries ramify. Soon, however, the structure becomes more and more divided into minute sacs or alveoli, in the walls of which the capillaries ramify so that the amount of aerating surface is enormously increased and the gaseous exchange made correspondingly easy.

With the development of the lungs special means must be provided for creating the necessary vacuum by which the air is to be drawn in. In the lower vertebrates (reptiles) among whom the breathing is slow and not very regular this is accomplished by the combined movements of many of the body muscles, but in the higher vertebrates the body cavity is divided by a transverse muscular partition, known as the diaphragm, whose contractions and relaxations are the chief source of the respiratory movements.

The Excretory System.—Vital activity, being a chemical process effected through the oxidation of protoplasm, is inevitably attended with the formation of combustion products. Of these the organism can make no further use, partly because their molecular structure is more stable than that of the protoplasm itself and partly because the energy required to resynthesize them

would be equal to the whole value thus gained. The effete matter is, therefore, a useless encumbrance to the organism, and when derived from nitrogenous compounds is injurious if retained, so that we find even the most lowly creatures eliminating or throwing off waste products in some form or other, the process being known as *excretion*.

As nearly all of the lowly forms of life are aquatic, their excreta are easily carried away by transfusion. In the corticate protozoa they may be suddenly eliminated through an anal pore in the ectoderm.

Primitive metazoan animals whose cells are in two layers, one outer in contact with the water of their habitat, the other, inner, in contact with the water alternately sucked in and forced out of the gastric cavity, as in hydra, or carried through in a continuous stream, as in the porifera, need no special contrivance for the removal of their cellular excrement which is transfused or ejected from the cells.

It is, therefore, not until structural complexity embracing a separation of the blood from the gastric contents is reached and the cells become so numerous that many of them are remote from both surface water and watery gastric contents, that some special contrivance by which the cellular waste products can be discharged is required. It is also only at this time that a separation between the waste that results from indigestible remnants of food in the gastric cavity and the waste that results from cellular metabolism becomes clear. The former, remaining in the alimentary organs, is discharged through an anal orifice; the latter, collected by the blood, is eliminated through certain lateral pores along the sides of the animal's body. In the description of the circulation of the unsegmented worms it was shown that the contents of the water vascular system in part returns to the digestive organs, but that a small part of it escapes through superficial pores of the skin. This is probably the most primitive form in which excretion

appears as a distinct function. It is not, however, quite so simple a function as would appear at first sight, for upon examination it is found that the fine branches of the water vascular system by which the circulating pabulum is conveyed to the surface do not terminate in simple openings, but in specialized cells of the dermal covering of the animal, known as "flame-cells"—so-called because an appearance suggesting the flickering of a flame is caused by the movement of vibratile cilia situated in vacuoles of these cells. The tubules terminate in vacuoles of these cells which seem

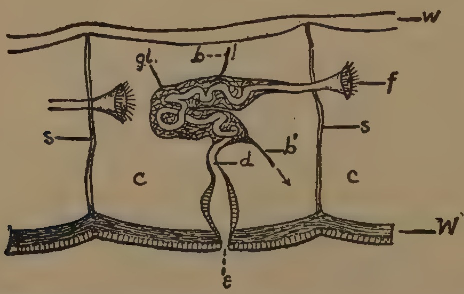


Fig. 55.—Diagram of a nephridium (simple kidney tubule) of a segmented worm. b, b^1, blood vessels; *c*, cœlome; *d*, duct of the nephridium; *e*, external opening; *cf*, ciliated funnel opening into cœlome; *gl*, glandular or secreting portion; *s*, septum; *W*, body wall composed of longitudinal muscle fibres, circular fibres, and epithelial layer; *w*, wall of gut. (*Galloway*.)

to carry on the excretory function. It is not a mere percolation of fluid through pores with which we have to do, but a function of certain specialized cells.

In the *annulata* we find special organs of excretion, known as *nephridia*, a pair of which is found in each segment. Each nephridium consists of a much convoluted epithelial-lined tubule which begins in a funnel-shaped ciliated orifice opening into the cœlomic cavity of the animal and directed anteriorly. This gathers up the body fluids and passes them through the convoluted portion of the tubule from which they eventually escape

through an external opening or pore. The blood in the vessels circulates through a vascular plexus about the convoluted portion of the tubule permitting its cells to take up the offensive substances and transmit them to the fluid constantly passing through the lumen. Here we have a most important and interesting specialization and differentiation of cellular activity, the sole function of these complicated organs being the absorption of waste products from the blood and their elimination from the animal.

This plan of having a tubular gland whose epithelial cells secrete the solids which are carried out by a passing current of water finds no improvement as the scale of zoological life is ascended. There are various modifications seen among special groups of animals, as among the crustacea, where special excretory glands are situated near the mouth parts and are developed upon a different principle, but in the main the only difference between the nephridium of the annelid and the kidney of the vertebrate is to be found in the number of component elements and the exact means by which the watery part of the excretion is provided.

The chief excretory organs of the vertebrates are known as kidneys, which upon superficial examination appear highly complex, though upon investigation are easily resolvable into a combination of units each of which is a tubular structure whose epithelial cells secrete the solids which are washed away by the water supplied by a capillary tuft at its commencement. Thus each structure unit in the mammalian kidney is the homologue of the nephridium of the worm.

Innervation and Coordination.—As structural differentiation and specialization increase and that cellular independence of the primitive composits, by which any cell seems able to assume any function, gives place to organized structure in which certain cells are set aside for the performance of single functions, means of communication between the different cell groups becomes

advantageous. Among animals, where movement is of prime importance, it becomes indispensable. The more highly specialized any cell group becomes, and the more completely isolated it becomes in consequence, the more imperative becomes the necessity for communication, control, and coordination.

In loosely organized cellular combinations, such as Epistylus and Microgromia, little advantage is to be gained for one cell by impulses derived from others, though the general irritability and conductivity of the protoplasm may enable impulses to pass from cell to cell. When one cell in such a simple colony is disturbed, a defensive reaction is manifested by its fellows, and in the case of Carchesium may result in escape from danger through contraction of the stalk. In such cases, as well as in the sponges and in hydra, the threatened danger is, however, usually of little importance to other cells than those immediately menaced by it. If those attacked should be destroyed—a portion of the sponge torn away or a tentacle of the hydra bitten off—the whole organism is scarcely affected and the damage is soon repaired. The same conditions obtain among plants, so that the entire development of the plant kingdom has progressed without any regulating or communicating—*i.e.*, nervous —mechanism. The importance of movement among animals has been dwelt upon, and we find means of controlling it making their appearance very early. Thus, of the ectodermal cells of hydra we find that though it is probably true that all of the cells are sensitive—*i.e.*, irritable—certain of them, called *neuromuscular* cells, exceed their fellows in sensitivity and contractility, and probably act as guides or indicators by which movements, especially of the tentacles, are directed.

Among the higher cœlenterates these ectodermal cells appear to transmit the impulses they receive to certain specialized "nerve cells" subjacent to them, and these, in turn, excite muscle cells through the mediation of certain fibres extending from one to the other.

Thus the interval between the protozoan, whose substance is irritable, and the metazoan with specialized receptive or sensory cells, nervous or controlling cells, and communicating fibres, is quickly spanned and the foundation of the nervous system laid.

It is important to note that the purpose of the primitive nervous system seems to be to correlate external impressions with movements directed toward the capture of food or escape from enemies. When such movements embrace the cooperation of various members, they can only be successfully performed when appropriate impulses are sent to them. It is, therefore, imperative that some portion of the developing nervous system develop disproportionately to the rest and become the centralizing and coordinating organ or *brain.* The brain is not only the centre from which impulses proceed, but also that in which they are received, analyzed, coordinated, and utilized. The analysis and utilization of impressions is to us synonymous with *consciousness,* but it is only after the coordinating centre arrives at a certain degree of complexity and becomes the seat of multifarious impressions and responses that anything meriting the term *consciousness* can be attributed to the animal.

The nervous system of an unsegmented worm consists of a brain in the form of an aggregation of nerve cells at the anterior end. From it two lateral nerve trunks extend to the tail, becoming smaller as they recede from the brain, evidently through the loss of fibres that are given off to the muscular tissue in due course.

The segmented worms differ in that there is a pair of nervous ganglia for each segment,, connecting with one another and with those of the adjoining segments by delicate bundles of fibres. In addition to these ganglia nerve cells are found here and there. In such animals each segment may be said to possess its own brains, though the anterior brains or ganglia, being the largest

and often fused to make one mass. This chief brain is, however, by no means indispensable to the animal, for it not infrequently suffers the loss of some of the anterior segments with the brain (as when birds seize hold of earth-worms and break them off), but is subsequently able to regenerate the lost segments, including the brain.

This arrangement, a double chain of intercommunicating nervous ganglia corresponding in number to the segments of the body and increasing size and importance of the anterior ganglia by which the brain is formed, constitutes the foundation of the *central nervous system* throughout the remainder of the zoological scale.

But in transferring our attention from the surface of

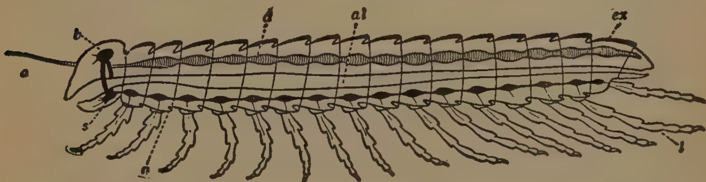


FIG. 56.—Diagram to express the fundamental structure of an arthropod. *a*, antenna; *al*, alimentary canal; *b*, brain; *d*, dorsal vessel; *ex*, exoskeleton; *l*, limb; *n*, nerve chain; *s*, subœsophageal ganglion. (*After Schmeil.*)

the body, where the nervous tissue first makes its appearance in the lowly forms of life, to the skull and spinal canal where it concentrates in the highest forms, the vertebrates, it must not be forgotten that while the improvement in the central nervous system has been in progress, there has been a no less remarkable improvement in the peripheral nervous system among whose specializations must be embraced all the organs of the special senses as well as the various nerve endings in muscles and glands.

When we come to consider this fact, it appears as though the development of the peripheral nervous system and the improvement of the organs of special sense contribute largely to the elaborate and complex develop-

ment of the central system in which the information they bring from the external world is received and utilized.

The brain of the higher animals receives impulses

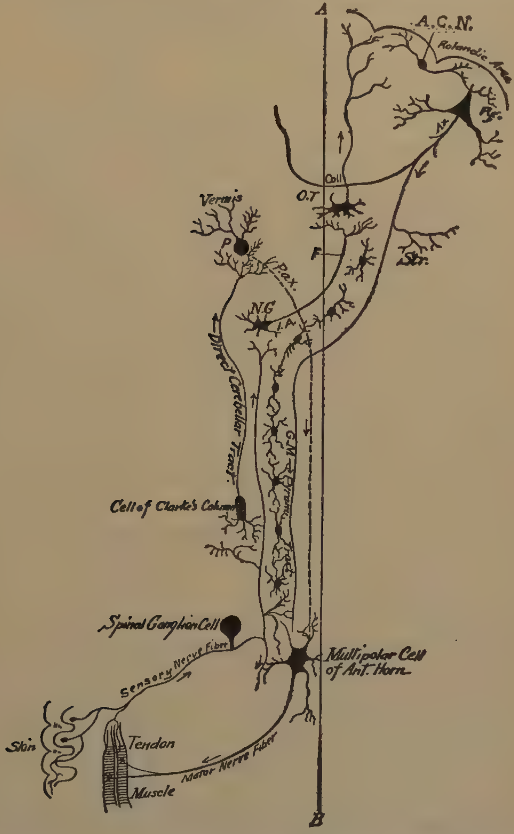


Fig. 57.—Scheme of reflex nervous action. Relationship of cells and fibres of brain and spinal cord.

which express themselves as sensations known as touch, pain, temperature, scent, taste, sight, and hearing. From the organs in which these impressions originate

an enormous number of nerve fibres connect with the brain, while to utilize the impressions a second group of fibres must connect the receiving cells with many other parts of the brain, and a third group of fibres leaves the brain in efferent course to apply the information in some such form as muscular action, for example, to the general good of the body as a whole.

It is difficult for one not acquainted with the details of nervous structure to conceive of the complexity of nervous activity arising in the course of a single and apparently trifling act. A few moments ago, having clipped some papers, you carelessly laid the sharp pointed scissors on the desk where a little later they were covered with some papers and a blotter. Moving your hand to brush the accumulation aside, you felt a sharp prick, found your hand involuntarily drawn away, and recognized that you had unexpectedly injured yourself. The point of the scissors touching the skin stimulated a peripheral nerve ending in so violent fashion that a double excitation followed, almost simultaneously registering pain in the receptive centres of the brain and stimulating a motor centre in the spinal cord by which an impulse was sent out to the muscles of the arm which was quickly drawn away by their contraction. In the meantime, the metal impression is being rapidly passed about from cell group to cell group until it arrives at a group of cells formerly stimulated in the same manner which now feebly revive the sensation, as one produced by a sharp object, and then to another group of cells which recall the scissors, and from these to others by which you become reminded of all that was done a short time before and that you had left the scissors on the table. The revived memories in these nerve cells thus define themselves as thoughts, appearing at first with such rapidity that they were very indistinct, but becoming more and more clear as time is allowed for each to arise, and as attention is directed toward it. Indeed, if no means of interrupting the course of nervous dis-

charges arising in the brain in this manner is adopted, and if no new and lively impression is received, the memories aroused in one group of cells after another continue along in an orderly sequence, as, for example, self-reproach for the carelessness shown in leaving the scissors on the table, the advantage of blunt over sharp scissors under such circumstances, the maternal admonition to order and carefulness often expressed in early days, and so on and on.

If what may be regarded as a relatively simple act is attended with such complex and correlated nervous activity, how much greater it becomes when some relatively complex act is considered. Thus from the garden comes a stimulus that excites the nerve endings in the mucous membrane of the nose and is transmitted to the appropriate cells of the brain which receive the impression as "*perfume of rose.*" When this impression has been properly registered, you turn, look out of the window and see—receive a visual impression of—a rose. How beautiful! you must go and pick it. Impulses now descend from the brain to the spinal cord, by which a succession of semi-automatic movements is initiated. Thus, you first rise from your chair, then put on your hat, then open the door, then walk through the garden, and then pluck the rose which you place in your buttonhole. Each of these acts is semi-automatic because it can be performed semi-consciously, that is, without special attention, having so often been performed before as to have become thoroughly coordinated. Who thinks what he is doing as he walks along the street? The action is thoroughly coordinated and purely automatic, but it is not so with the infant learning to walk, and it is not so with some new method of progress, as, for example, walking upon stilts or gliding upon skates. An adult learning such tricks is painfully conscious of the lack of the proper coordination for the required movements.

Presumably the automatic movement has the same

foundation as the thought. Each is a cell memory. A cell or group or cells, having been once impressed, recalls the same impression and passes it around in the same manner, producing definite impressions upon group after group. The act of walking is not simple; the movements of the limbs in balancing the heavy body as its centre of gravity is alternately disturbed and recovered, is extremely complicated, and necessitates the combined efforts of many muscles brought into action singly or in combination in orderly sequence. Yet this can be achieved without conscious thought, because through long practice the cells remember the lessons they have learned and carry them through without a mistake. How complicated is the performance of a fine pianist! Does he know each note struck? Not at all; the whole is a series of wonderfully well-coordinated, highly complex, automatic acts resulting from the precise activity of well-trained nerve cells whose memories do not fail. How difficult to learn the piano where the eye reading the notes and signs and the fingers interpreting them must work in harmony! With what tears and pains does the child learn to drum some simple composition!

Thus, a consideration of the functions of the nervous system inevitably brings us to psychology, and we are tempted to inquire whether there is any essential difference between such motor automatism with its coordinated movements and the psychic movements we know as thoughts. The answer should be no. There are no differences other than may be accounted for by the materials and the mechanism. Thought seems to be a succession of nerve transmissions following one another in endless number and in orderly sequence, having their source in an external impression. Once set in motion, the stimulus passes on and on, the memory of each cell reviving some other related memory in another cell. Experience shows that these memories arise simultaneously in many cells, though the more lively are usually developed to the exclusion of the others. Each thought

has its beginning in some external impression. Those who doubt this may amuse themselves by endeavoring to create something in thought.

It is not the purpose of this writing to indulge in the deeper problems of psychology or to enter the domain of metaphysics. Consciousness, the highest of the nervous phenomena remains unexplained. As, however, consciousness implies the possession of those special senses by which knowledge of the external world can be attained, and is discovered only after a certain intellectual development has been reached; as it is apparently absent in idiots and may be lost in disease, injury, or anæsthesia, there can be no doubt but that it is a function centred in the nervous system, and that it depends upon the complexity of that system and the correlation of its cell impressions or memories.

But the higher animals not only live in adjustment to the external world; they have internal organs whose functions are indispensable, and upon whose coordinated activities the life of the whole body depends. For these there must be governing mechanisms, and chief among them we again find the nervous system. Here, however, automaticity of operation and properly correlated action are the chief requirements. These functions progress without intellection. The nervous arrangements by which this work is done, therefore, forms an almost independent system, the *sympathetic system*, by which the organs are automatically innervated. Thus, the heart beats continually—automatically—by virtue of its inherent ganglia, though it communicates with the central nervous system through the vagus nerves and is impressed by general psychic conditions. It is difficult to trace the inception of this part of the nervous system, as automatic action, such as it supplies to the organs of the higher animals, is one of the first functions to make its appearance in the lower forms of life. No separation of the two branches of the nervous system into sensory-motor and sympathetic systems can be

made out in animals lower than the arthropods, with the single exception of the leeches.

The increasing complexity of the central nervous system depends in large measure upon the continually increasing importance of the organs of special sense, which improve in quality and number and require means by which the impulses they receive may be transmitted to and from the common utilizing and governing centre.

It might seem as though the tactile sense, that through which the organism is able to recognize the existence of objects external to itself ought to be the first of the special senses, yet it must not be forgotten that the most primitive forms of life are not only subject to the injurious or beneficial effects of contact with objects, but are at the mercy of every force known to the physicist so that inability to avoid the harmful and avail themselves of the useful must result in death. Vast numbers of organisms must die every moment because of their inability to discriminate, and it must be only by the force of the numbers developed when conditions happen to be favorable that such are able to persist at all.

In the absence of visible means of receiving impressions from the external world, the behavior of these primitive forms is said to be controlled by forces already described as *tropisms*.

Looking in retrospect over the gradations of life between the highest and lowest of living things, both animal and vegetable, one is struck by the fact that accident has much to do with success or failure in surviving in the midst of what appear to be antagonistic influences. At first thought it might seem as though the necessity for sensory organs for the appreciation of external conditions, and by virtue of which a suitable environment might be sought and an unsuitable one avoided, enemies eluded and food captured ought to be indispensable to successful existence, yet the far

greater number of living beings belong to the vegetable kingdom, which has achieved its success entirely without such aid. With immensely restricted powers of movement, defenseless, as a rule, with no nervous system, no sensory organs, no consciousness, by purely vegetative development, through favorable accidents, multiplying in vast numbers, dying in vast numbers, the chief support of the animal world which feeds upon them, these organisms have covered the earth and filled the waters in inconceivable numbers and endless variety.

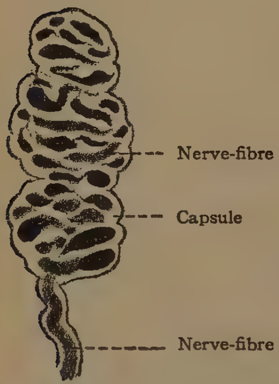
But, as has been said, the animal world developed along different lines and almost immediately began to profit by the constructive energy of the plants utilizing their protoplasm to their own advantage, and apparently finding it more easy to work with materials already prepared than to manufacture for themselves. Thus, animals became predatory and have continued to nourish themselves exclusively at the expense of plants and each other.

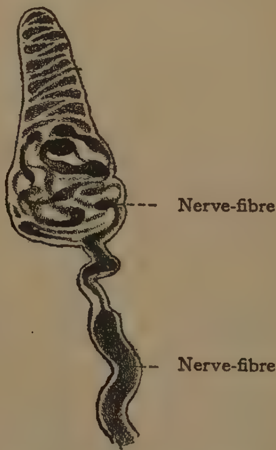
To find food already prepared may require long excursions, hence the animals, with few exceptions, developed the power of locomotion. The food must be found, must be caught, must be transformed, hence in animals are found organs that would be as useless as they are unknown to the plants. To find, to recognize, to seize, to ingest, to digest, to circulate, to assimilate, are all functions attended with more or less complexity and for which special organs are indispensable. To meet these requirements, organs of special sense appear, though not in an order that makes their evolution simple or easy to follow. It might be imagined that the necessity for all of these desirable functions was simultaneously experienced and that they began their development about the same time, for one no sooner finds himself well on his way to trace the beginnings of the sense of touch, than he finds the foreshadowings of the organs of vision and of other special senses.

With this confusion of beginnings in mind, the follow-

ing outline of the appearance and evolution of the special senses is offered.

Touch.—The tactile sense can be traced to the irritability of living substance. It begins without special organs as the phenomenon of thigmotropism. The pseudopods of the rhizopoda are thigmotropic, hence tactile and discriminating. But in composite organization it is not sufficient that the cells shall be equally irritable and similarly impressed by external agents. Division of





Figs. 58, 59.—Meissner's corpuscle from man; × 750. (*Böhm, Davidoff, and Huber.*)

labor begins, and it becomes necessary for a more elaborate response to follow certain stimuli than could be effected by cells acting individually. Moreover, certain cells are so situated as to be, above their fellows, susceptible to external agents, so that we need only ascend to the cœlenterates to find the ectodermal cells more sensitive than others, and to find a mechanism by which the external impressions are communicated to groups of cells, by which they are to be utilized, through intermediate nerve cells. Though the sensory apparatus is

so simple that it is difficult to account for all that is accomplished, it already has discriminative powers. Useful objects when touched are apprehended by the tentacles of the cœlenterates, indifferent objects are neglected, harmful objects may be avoided.

So soon as a central nervous system appears, nerve

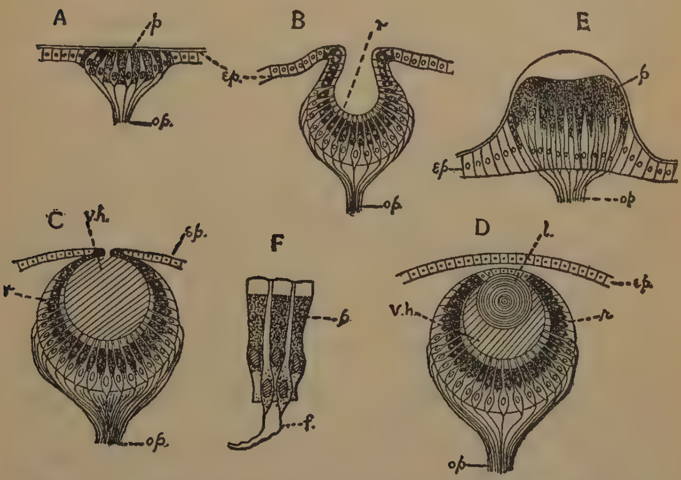


Fig. 60.—Diagrams showing some of the stages in the increasing complexity of the simple eye in invertebrates. A, Simple pigment spot in epithelium have nerve-endings associated with pigment cells (as in some medusæ); B, pigment cells in a pit-like depression (as in *Patella*); C, with pin-hole opening and vitreous humor in cavity (as in *Trochus*); D, completely closed pit, with lens and cornea (as in *Triton* and many other Mollusks); E, pigment area elevated instead of depressed lens of thickened cuticula (as in the medusa, *Lizzia*); F, retinal cells more highly magnified. *ep*, Epidermis; *f*, nerve fibre; *l*, lens; *op*, optic nerve; *p*, pigment cells; *r*, retina; *v.h*, vitreous humor. (*Galloway*.)

fibres connect the sensitive cells upon the surface with controlling centres, and more exact conduction and distribution of impressions become possible. The peripheral apparatus continues to specialize until the sense of contact is capable of differentiation from the sense of harmful contact or pain, and eventually into a great variety of impressions, pleasurable, painful, thermic,

etc. But such development is not possible until there appear in the superficial tissues highly specialized nerve endings (Meissner's corpuscles) adapted to the reception of the particular impressions, and in the central nervous system that complex adjustment of white and gray matter by which the impressions are received and appreciated.

Sight.—If we define sight as the ability to appreciate light, we must admit that it makes its appearance in the most simple form as the phototropic sensitivity of protoplasm. If, however, we mean by the term, the recognition of light by the aid of an eye, we are almost as badly off because of the uncertainty as to what shall constitute an eye. In its broadest sense, an eye is an organ formed for the appreciation of light, to the waves of which it is specially sensitive. Such an organ may be extremely simple in structure, totally devoid of the power of forming images of external objects, and consist merely of a group of pigmented cells, as for example, the eye-spot of Euglena or the eyespots in the higher coelenterates. The latter connect with subjacent nerve cells, thus forming a true sensory organ, though in what manner the impressions received are utilized is difficult to understand.

Similar eyes are also found in the flat worms, though in these the nervous elements become more numerous, and instead of being upon the surface of the body, the organ becomes situated in a more or less pronounced pit or depression from which the nervous cells radiate, the fibres with which they are connected converging to form an optic nerve. Eyes of this kind persist among the arthropods, though more highly specialized eyes are also present.

From such eyes it is a simple step to the *camera-eye*, in which the nervous elements surround a spherical space into which the light comes through a minute opening, the homologue of the pupil, causing an inverted image to fall upon the more numerous nerve elements and

so effecting a differentiation of lights and shadows. The next specialization consists in an outer transparent cuticular covering or cornea, the presence of a clear jelly in the space—vitreous body—and eventually of a lens by which the light rays are refracted and accurately distributed. There are many variations of the apparatus, however, for in the arthropods it develops into a congeries of what might be described as visual units, as in the compound eye of the insects which are made

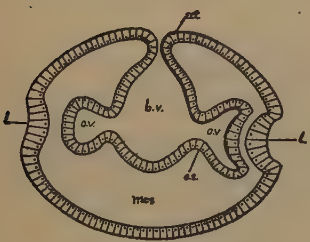


Fig. 61.

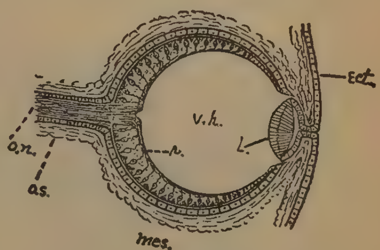


Fig. 62.

Fig. 61.—Diagram illustrating the early development of the vertebrate eye. (*Galloway.*)

b.v, The brain vesicle formed by the invagination of the ectoderm, *ect.*; *mes*, mesodermal tissue; *os*, optic stalk; *ov*, optic vesicle, a portion of the brain vesicle; *l*, lens. The right side of the figure shows a slightly later developmental stage than the left.

Fig. 62.—Diagram illustrating a later developmental stage of the vertebrate eye. *On*, optic nerve; *r*, retina; *v.h*, vitreous humor; *l*, lens; *ect*, ectodermal tissue; *mes*, mesodermal tissue. (*Galloway.*)

up of hundreds of units consisting of an outer ectodermal transparent cuticle or cornea, beneath which are pigment cells with subjacent nervous elements in groups. The images gathered by such eyes may be regarded as a kind of mosaic made up of many small bits. There can be no accommodation and no perspective. From such eyes great bundles of nerve fibres pass to the optic lobes of the brain, so increasing its complexity.

Among certain mollusks, such as the cephalopods, the eye forms a beautiful and striking organ superficially

resembling the vertebrate eye, but having certain essential differences, for the retinal nerve cells are directed toward the centre of the globe and are outside of the pigment layer, while in the more perfect vertebrate organ the nerve endings are directed away from the centre and the pigment layer of the retina is outside.

As the structure of the eye increases in perfection the number of nervous elements increases greatly, and the complexity of the central nervous system is increased both by the increased number of fibres it receives and

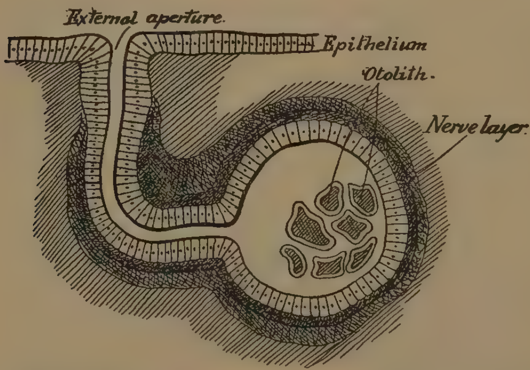


FIG. 63.—Section through the otocyst of arenicola. (*After Ashworth and Gamble.*)

the number of cells with which they communicate, so that the new centres, optic lobes, and optic thalami make their appearance.

Hearing.—In this sense we doubtless have to do with a specialization of thigmotropic irritability to vibrations set up in the media in which the organism lives. The inception of the organs by which such vibrations are originally recognized is unknown. The first organs that can be definitely made out are found among the cœlenterates. In certain jelly-fishes minute vesicles are found situated at the edge of the disc, each contain-

ing one or more small crystals or concretions. These vesicles are known as *otocysts*, the crystals as *otoliths*. Similar organs, by which vibrations are caught and transmitted to the central nervous system, occur among worms and mollusks. They are usually minute, difficult to find, and may be situated in unexpected places, as, for example, in the clam, where they occur in the so-called "foot." In the crustacea they are extremely peculiar and consist of small sacs formed by an invagination of the integument, filled with fluid, provided with

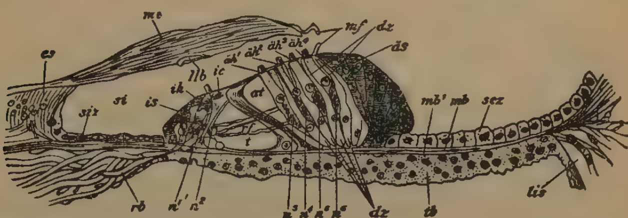


FIG. 64.—Transverse vertical section of Corti's organ of a man twenty-nine years old. *es*, Limbus laminæ spiralis; *mc*, membrana tectoria; *Hb*, Hensen's striæ; *mf*, fibres of attachment of the membrana tectoria to the zona tecta; *si*, sulcus spiralis; *siz*, epithelium of the sulcus spiralis; *is*, inner supporting cells; *ic*, inner rod cells in connection with the outer rod cells, between which is seen the tunnel (*t*) of Corti; *ih*, inner hair cell; $\ddot{a}h^1$–$\ddot{a}h^4$, outer hair cells; *dz*, Deiters' cells; *äs*, Hensen's supporting cells; *rb*, nerve fibres of the ramulus basilaris; n^1–n^6, outer bundles of the spiral nerve fibres; *rf*, radiating tunnel fibres; *at* inner part of Nuel's space; *mb*, upper layer of the membrana basilaris; *mb′*, lower layer of the membrana basilaris; *tb*, layer covering the tympanic surface of the membrana basilaris; *lis*, ligamentum spirale. (*Gruber, after Retzius.*)

many small hair-like projections. Grains of sand entering from the exterior seem to be essential to the perfection of the apparatus, though sometimes concretions of lime salts form in the organ and constitute an improvement.

An advance in the development of the apparatus is found among the insects whose "ears" or chordotonal organs are provided with a tympanic membrane. These organs are large, and may be situated upon the sides of the abdomen or upon the anterior tibiæ. Sometimes, however, no auditory organs can be found when

it is supposed that the antennæ act as vibration-receiving organs as well as organs of touch and smell.

The vertebrate ears are two in number, vary in elaborateness, and are situated in special cavities of the cranial bones. The elaborate auditory mechanism found in mammals is divisible into an external ear to receive the sound waves, a middle ear or "drum" to intensify them, and an internal ear containing the actual auditory nerve fibres spread out in what is called the "organ of Corti."

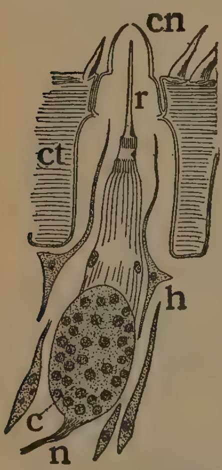


FIG. 65. — Longitudinal section of antennal olfactory organ of wasp, *Vespa*; *c*, Olfactory cell; *cn*, olfactory cone; *ct*, cuticula; *h*, hypodermic cells; *n*, nerve. *r*, rod. (*After Hauser.*)

From the simple and complex ears nerve fibres pass to the brain, communicating with special auditory centres and so increasing its complexity both by the addition of fibres and cells.

Smell.—This sense may be regarded as an amplification of chemotropic irritability, by virtue of which certain superficially situated cells specialized for the purpose receive and transmit chemical impulses to the central nervous system.

The primitive means by which such impulses are collected are entirely conjectural. In the absence of distinct organs to which such a function can be assigned we are in doubt as to whether the lowly organisms possess the sense of smell or not. Even among the insects no definite organs for the purpose can be found, and yet the rapidity with which bees find honey and certain carrion insects their concealed food suggest that such insects possess this sense to a high degree. The antennæ seem to be the olfactory organs and possess nerve endings supposed to be organs of scent, though certain organs

at the base of the wings in some flies and upon the caudal appendages of other flies may be olfactory in nature.

Among vertebrates the sense of smell is always situated in the nose, upon the mucous membranes of which the olfactory nerves distribute in varying number according to the activity of the sense. These nerves communicate with the olfactory lobes of the brain and constitute an added source of complexity to that organ.

Taste.—This is another amplification and specializa-

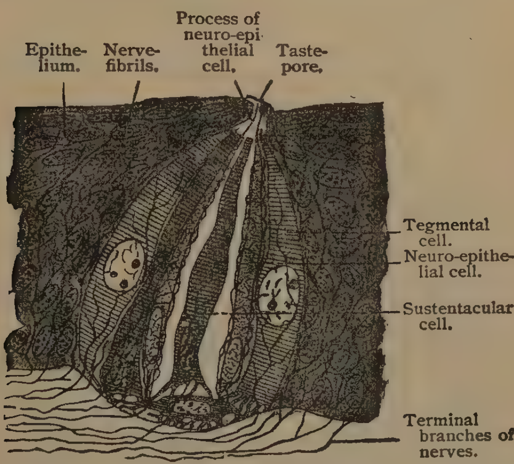


FIG. 66.—Schematic representation of a taste-goblet. *Böhm, Davidoff, and Huber.)*

tion of the chemotropic irritability of protoplasm. As in the highest animals, this sense resides in certain distributed nerve endings in the tongue and palate, does not take the form of a visible sensory organ, and so is not easy to localize. Little can be learned about it in animals whose structure is essentially dissimilar.

It would seem as though it must be almost universal among animals as the chief means of discriminating between what is useful and what is useless as food, yet

in this regard it is easy to fall into error for in man we find the taste an unsafe guide, many things not pleasant to the palate being serviceable for food and some that taste quite agreeably being injurious or even poisonous. It may be, therefore, that taste is not a common sense, and that other means of discriminating between useful and useless things are provided. However this may be, when the sense exists there must be specialized nerve endings to be impressed, fibres to convey these impressions to the brain, and centres where they are to be received and retained or utilized, and the fact holds good that with each sense the general complexity of the central nervous system is increased.

References.

Thomas H. Huxley: "Anatomy of Invertebrated Animals," N. Y., 1885. "Anatomy of Vertebrated Animals," N. Y., 1886.

W. T. Sedgwick and E. B. Wilson: "An Introduction to General Biology," N. Y., 1895.

A. S. Packard: "Zoology" N. Y., 1895.

A. T. Masterman: "Elementary Text-book of Zoology," Edinburgh, 1902.

T. W. Galloway: "First Course in Zoology," Phila., 1906.

Anton Kerner von Marilaun: "The Natural History of Plants." Translated by F. W. Oliver, N. Y., 1894.

E. Strasburger, F. Noll, H. Schenck, and G. Karsten: "A Text-book of Botany," translated by W. H. Lang, N. Y. and London, 1908.

J. Y. Bergen and B. M. Davis: "Principles of Botany," N. Y., 1906.

T. J. Parker: "Lessons in Elementary Biology," London, 1893.

CHAPTER VIII.

REPRODUCTION.

The most simple living organisms multiply by division with or without karyokinetic changes of the nucleus. In most cases such division is binary; that is, results in two of the same general kind; but in special cases, sporulation, it is multiple and gives rise to a varying number of offspring that differ from the parent in being much smaller and also in certain cases in being obliged to pass through a succession of changes before reaching maturity and parental resemblance. Other lowly organisms reproduce by a different method known as *gemmation* or *budding*. In these forms, of which the yeasts will serve as examples, the adult cell throws out a minute bud or excrescence which grows larger and larger and more and more like the parent. As the bud grows, the nucleus of the cell divides by some modification of the karyokinetic process, one-half being retained in the parent cell, the other half passing into the bud which eventually separates as a new individual.

Inasmuch as both division and gemmation result in the multiplication of a single cell, these methods are described as *asexual* or *monogenetic reproduction.*

The ability of any cell to multiply depends upon its inherited impulses and upon its conditions of life. Thus, though multiplication is continually in progress among the unicellular forms of life, and characterizes the great body of cells among the metaphyta or higher plants, it is found among the metazoa or higher animals only during the period of growth. When maturity—*i.e.,* the full size and complete differentiation—has been

reached, most of the higher animals cease to grow and most of their cells to multiply.

Unrestricted powers of multiplication are indispensable

Fig. 67.—Sporulation. Developing stages of Coccidium oviforme. 1, Young intracellular organism, somewhat elongated; 2, an epithelial cell containing two young organisms, undifferentiated in type; against the surface of the larger organism is a disc of eosin-staining substance; 3, 4, 5, stages in the development of the schizont; 6, merozoites as seen in stained smears; 7, merozoites arranged in a rosette, about the restkörper. (From drawings made with camera lucida, Zeiss comp., ocular No. 4, 1/12 homogeneous immersion.) (*After Tysser.*)

Fig. 68.—Budding yeast cells (Saccharomyces cerevisiæ), showing four successive stages manifested by the nuclear apparatus. The large pale sphere is the nuclear vacuole, the small dark sphere the nucleolus.

to the lowly forms of life as the sole means of perpetuating their kind. But among the metazoan animals where the cells are but units in a complex structure, little is to be gained by the indefinite growth of the

individual through the unrestricted multiplication of his component cells, and the perpetuation of the kind must be secured through *discontinuous growth—i.e.*, off-

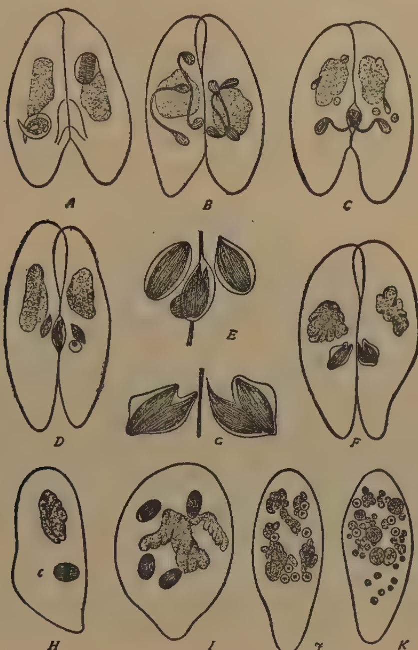


FIG. 69.—Conjugation of Paramœcium caudatum. [A–C, after R. Hertwig; D–K, after Maupas.] (The macronuclei dotted in all the figures.) A, micronuclei preparing for their first division; B, second division; C, third division; three polar bodies or "corpuscules de rébut," and one dividing germ-nucleus in each animal; D, interchange of the germ-nuclei; E, the same, enlarged; F, fusion of the germ-nuclei; G, the same enlarged; H, cleavage-nucleus (*c*) preparing for the first division; I, the cleavage-nucleus has divided twice; J, after three divisions of the cleavage-nucleus; the macronucleus is breaking up; K, four of the nuclei enlarging to form the new macronuclei.

spring. In such animals it is not through the *somatic* or general body cells, but through a certain few *germinal* or *reproductive* cells, early set aside and highly specialized for this purpose, that this is made possible.

Such cells may be given off at any time after the parent attains to a certain development, after the completion of which, the purpose of life having been fulfilled, it usually becomes decadent.

Among the most lowly living things, both animal and vegetable, growth is regularly followed by fission or budding. But as the higher organisms are reached, and the foreshadowings of organs appear, multiplication becomes complicated by conditions not clearly understood, though no doubt of deep biological significance.

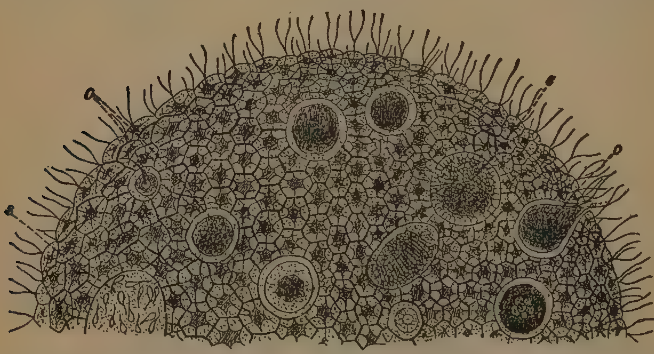


FIG. 70.—Volvox globator, showing the uniform and unspecialized character of the cell structure. The large cells, *o* and *s*, the oocytes and spermatocytes, are the reproductive cells and alone show specialization. (*Lang.*)

Thus, when paramœcia are kept in a small aquarium under what seems to be appropriate conditions multiplication by fission proceeds for a certain time, after which the organisms appear to languish, cease to multiply, become inactive, and tend toward extinction. Indeed, not long after the appearance of these symptoms, the organisms do die and disappear.

But Maupas observed that if at this critical period the contents of two such aquaria are poured together, a phenomenon known as *conjugation* quickly takes place. Two organisms, presumably one from each stock become

attached to one another by what might be called their ventral surfaces—*i.e.*, the surfaces containing the oral apertures—undergo a partial fusion of the surface, adjust their cilia so that they move synchronously, and remain united for some time. This union is known as *conjugation* and during it a complicated interchange of cellular and nuclear substance takes place.

When this interchange is satisfied, the conjoined individuals separate and each again begins to multiply by

Fig. 71.—Epistylus umbellaria. Showing conjugating cells. (*After Graeff from R. Hertwig.*)

fission as though the virility of their respective strains had never diminished.

From this experiment we learn that material derived from two individuals, for some unknown reason, affords the cell greater vigor than that exclusively its own.

In many cases conjugation is an occasional phenomenon in which there are no essential differences between the cells participating; in a far greater number of cases there are such constant differences that it is possible to separate them into male and female elements or *gametes*. The development of sexual differences may or may not be incompatible with the continuance of reproduction

by fission, though *in general* it marks the end of the *asexual* or *monogenetic* and the beginning of the *sexual* or *digenetic* mode of reproduction.

As in the most simple forms of life, there are no visible, and probably no theoretical differences between the occasionally conjoining cells, so we find that among the primitive forms in which conjugation is constant, and special cells are generated for the purpose, the relation of these cells to one another is so close that they not infrequently descend from the same parent cell. Thus a spore of the malarial parasite having attained maturity, divides into a considerable number of spores which develop and again divide until eventually through this asexual mode of reproduction a great number of the parasites is produced, all the progeny of a single cell. By and by, however, a time comes when the mature cells cease to sporulate as usual, and develop into mature sexual forms, gametes, with which there is no further development unless conjugation of two such elements be permitted.

If, in this case, it should be argued that there is no certainty that the conjoining male and female elements are derived from the same parent because the patient may have a multiple infection, examples taken from the primitive vegetable world may be given to prove the case.

In the reproduction of Eurotium repens both the asexual and sexual methods may be observed. The former, which is accomplished through spores, may be looked upon as a kind of fission; the latter, after a definite conjugation, results in the formation of a peculiar perithrecium in which a smaller number of ascospores is developed. The formation of the perithrecia is not easy to follow. As described by de Bary, "they begin in the form of tender branches which at the termination of their longitudinal growth begin to twine their free ends in a spiral of four or six turns; the threads of the spiral gradually approach nearer together, until finally

they are brought into contact so that the entire end of the filament takes the form of a helix (the *ascogonium*). There then grow from the lowest part of the helix two or more small branches, which cling closely to the spiral. One of these quickly outstrips the others in growth;

FIG. 72.—Development of *Eurotium repens*. A, Small part of a mycelc with the conidiophore, *c*, and young ascogones, *as*; B, the spiral ascogone, *as*, with the antheridial branch, *p*; C, the same with the filaments beginning to grow round it to form the wall of the sporocarp; D, a sporocarp seen from without; E, F, young sporocarp in optical longitudinal section; *w*, parietal cells; *f*, the filling tissue (pseudoparenchymatous); *as*, the ascogone; G, an ascus; H, an ascospore. (*After De Bary*).

its upper extremity reaches the uppermost turn of the helix and *fuses with it*. The other branch or branches likewise grow upward along the spirals, shoot out new branches and gradually become so interlaced that the spiral is finally surrounded by an unbroken envelope. These branches divide slowly into septa perpendicular

to the surface and the envelope consists of short angular cells in which new septa appear parallel to the surface, so that the envelope thickens and is composed of many layers. The small sphere now formed is about 0.25 mm. in diameter; the outermost layer is yellow, whilst the

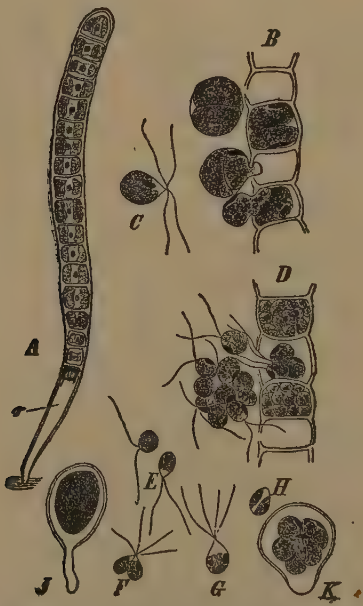


Fig. 73.—*Ulothrix zonata.* A, Young filament with rhizoid cell, *r* (× about 300); B, portion of filament with escaping swarm spores; C, single swarm spore; D, formation and escape of gametes; E, gametes; F, G, conjugation of two gametes; H, zygote; J, zygote after peried of rest; K, zygote after division into swarm spores. (*After Dodel-Port.* B–K × about 482.)

inner layers remain soft, and later are dissolved. The spiral, after a time, extends and throws out on all sides branched filaments which dislodge the inner layers of the envelope. These branches finally take the form of an *ascus*, eight spores being formed in each. After the breaking up of the *asci*, the spores lie loose in the

interior of the *perithrecium* and are liberated by the rupture of the fragile wall of the latter."

In this example the conjugation embraces two elements not only belonging to the same individual, but also to the same mycelial filament.

Among the algæ same interesting forms of conjugation of elements derived from the same parent may also be observed. Thus, in Ulothrix zonata sexual and asexual reproduction may be seen. The asexual reproduction is accomplished by swarm spores each of which is provided with four cilia. These are formed, so far as can be determined, by any cell in the filament of which Ulothrix is composed, and having escaped through an opening in the side of the cell are immediately ready to swim away and start a new growth resembling the parent. The sexual reproduction is accomplished through *gametes* which closely resemble the swarm spores except that they are smaller and possess but two flagella each. These likewise escape through an opening in the lateral wall of the parent cell, but proceed to conjoin, forming *zygotes* or fertilized cells, which draw in the flagella, become spherical, surround themselves with a cell wall and enter upon a period of rest, after which they divide into a number of swarm spores which in turn escape from the capsule and swim away to found new plants. In case the gametes are unable to conjugate, they may behave like the swarm spores and themselves found new individuals.

Here, therefore, we find a plant with such loose methods of reproduction that even its gametes or sexual cells may under certain conditions fail to conjoin, but carry out a *parthenogenetic* development—*i.e.*, germination without conjugation or fertilization.

Another interesting and instructive example is found in the self-conjugation of Vaucheria which might be likened to a form of *hermaphroditism* or bisexual nature of one individual. Here we have a filamentous alga whose terminal cell becomes specialized into a sporan-

gium containing a zoospore which escapes by rupturing the apex of its wall by means of a rotary motion. This zoospore is large enough to be seen with the unaided eye, consists of mass of colorless protoplasm containing numerous nuclei and is surrounded on all sides by cilia, two of which are given off opposite each nucleus, and is said by Strasburger to correspond to the collective individual zoospores of an ordinary sporangium. This zoospore

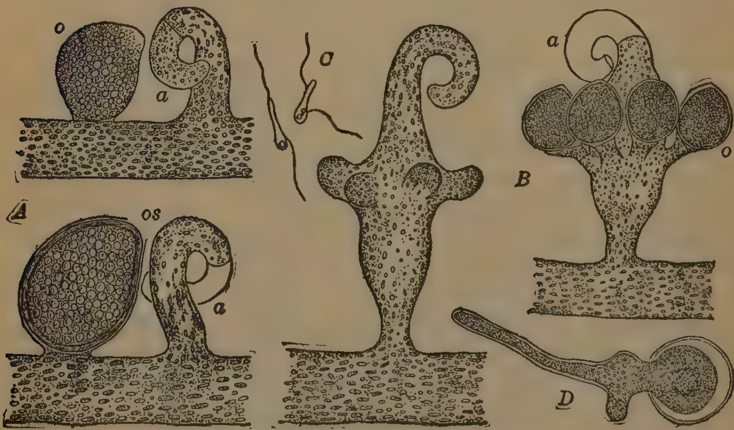


Fig. 74.—Sexual reproduction of the green felt (*Vaucheria*). A, *Vaucheria sessilia; o*, oogonium; *a*, antheridium; *os*, the thick-walled oospore, and beside it an empty antheridium; B, *Vaucheria geminata*, a short lateral branch developing a cluster of oogonia and a later stage with mature oogonia *o* and empty antheridium *a*; C, sperms; D, germinating oospore. (C, *after Woronin*; D, *after Sachs*.) (*From Bergen and Davis*, "Principles of Botany." Ginn & Co., publishers.)

immediately develops into a new plant. In addition to this and more important in this argument is the sexual reproduction. From the same cell of one of the filaments two small protuberances, the oogonium and antheridium, containing the female and male elements, respectively, make their appearance and soon develop as short lateral branches which become separated from the rest of the thallus. It is said that the oogonium at

first contains several nuclei of which all but one subsequently retreat into the main filament again before the septation is completed.

The oogonium eventually forms a rounded mass with a truncated conical projection of clear protoplasm on one side where it opens. The antheridium which is multinuclear and more or less coiled or like a hook is open at the tip. Its contents first break up into swarm-

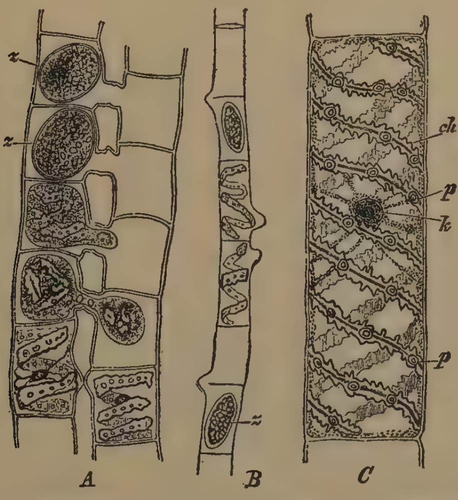


FIG. 75.—A, Conjugation of *Spirogyra quinina*. B, *Spirogyra longata*; z, zygospore. C, cell of *Spirogyra jugalis*; *k*, nucleus; *ch*, chromatophores; *p*, pyrenoid. (*Strasburger, Noll, Schenck, and Karsten.*)

ing spermatozoids which it then discharges together with its mucilaginous contents. The spermatozoids are very small, each being provided with a single nucleus and two cilia. They collect about the oogonium into which one of them eventually penetrates to fertilize it by the fusion of their nuclei. The oogonium then becomes converted into a resting oospore which eventually germinates with the production of a filamentous thallus. Here we find a

peculiar development of the phenomenon of conjugation by which in a certain sense the cell substance conjoins with itself.

Another curious form of conjugation is seen in Spirogyra, where two cells side by side in the same filament conjugate by the development of coalescing processes which are formed near their transverse wall. Here

FIG. 76.—Mucor mucedo. Different stages in the formation and germination of the zygospore: 1, Two conjugating branches in contact; 2, septation of the conjugating cells (*a*) from the suspensors (*b*); 3, more advanced stage in the development of the conjugating cells (*a*); 4, ripe zygospore (*b*) between the suspensors (*a*); 5, germinating zygospore with a germ-tube bearing a sporangium. (*After Brefeld.*)

again there can be no doubt but that the conjoining cells are the descendants of the same parent and so closely related as to make the advantage of the interchange of substance of problematical value.

From such indistinct differentiation of male and female substance, and from aberrant forms in which, as in Ulothrix, the gametes may either conjugate or

themselves go on to adult development, we pass to forms in which the conjoining cells must come from different individuals. Thus in Mucor mucedo the formation of zygospores follows the conjugation of cells from different colonies, never from the conjugation of cells from the same colony. The spreading mycelia of this mould, reaching the spreading mycelia of another colony may or may not conjoin according to the nature or conditions of the two. Thus when carefully examined it is found that they can be separated into two strains represented, respectively, by the signs + and −. Colonies of the + strain will not conjoin; colonies of the − strain will not conjoin, but + and − will conjugate and form zygospores. The actual steps in zygospore formation are not difficult to follow. The gametes are clavate terminal enlargements of the mycelial threads. As they come together the tips flatten and soon a short cell, the real conjugating cell or gamete, makes its appearance through the formation of a line of cleavage appearing a short distance from the point of contact.

The original mycelium is now known as a *suspensorium*, the conjoined cells as gametes. There may be one or two zygospores according to the subsequent development of one or both of the gametes. In cases where actual fusion of the gametes takes place, there can be but one zygospore; where a transfer of substance from one to the other occurs without fusion, two may form. The zygospores become surrounded with a thick membrane which, under favorable conditions, ruptures to permit the escape of the growing hypha. The advantage of conjugation in these cases is not clear, for the formation of spores surrounded by dense membranous envelopes—azygospores—may occur without conjugation.

Thus in examining the lowly forms of life, both animal and vegetable, we are struck by the growing tendency toward *amphimixis* or the digenetic mode of reproduction, the importance of which is shown by the ingenious means taken to bring it about, and the final disappear-

ance of all other forms of reproduction among the highest animals and plants.

As we have found the reproductive power a characteristic of living substance, so we find this power remaining among otherwise differentiated multicellular beings long after more simple forms have adopted sexual modes of development. Even after the differentiation of somatic and germinal cells has been effected, and germinal cells of two sexes established, the general tendency of the cells toward reproduction remains strong and shows itself in a variety of ways.

Thus, among plants, long after sexual reproduction has been established and even in certain forms in which sexual organs and seeds are produced, the asexual form of multiplication continues and may be the chief method of reproduction. The garlics, for example, produce no seeds, but only bulbs, and the banana, though it produces seeds, continues to grow chiefly through bulbous buds. Other plants, Chara, with well-developed sexual organs, produce but one, the female sex.

Among animals, although the asexual mode of reproduction is chiefly confined to the protozoa, we find it continuing among the cœlenterates and worms, both of which multiply by gemmation though eggs are also produced.

In this particular the hydra is more lowly than the sponges which multiply exclusively through eggs, because it continues to multiply by buds as well as by eggs. The buds appear upon the body wall as rounded eminences, which in the course of time become provided with tentacles, come more and more closely to resemble the parent, and finally separate themselves as new individuals. In addition, however, certain of the apparently undifferentiated cells of the ectoderm increase locally in number forming gonads which contain the germ cells, one group situated near the tentacles being the homologue of the testes of the higher animals, the other usually developed near the aboral end, forming

the ovary and containing the eggs. Spermatozoa are produced in large numbers by the testicular cells which mature before the ova (*protandrism*) and are liberated by rupture of the ectodermal covering. One ovum is

FIG. 77.—Colony of Obelia geniculata (magnified). (*After Masterman.*)

usually all that matures in the ovary. It takes an amœboid form also escaping by rupture of the ectodermal layer, protruding between its cells, in which position it is reached by the spermatozoa, one of which conjugates with it. When thus fertilized, it loses its amœboid

movement, becomes encysted and remains dormant for several weeks after falling from the parent.

The hydra is thus seen to develop in itself both male and female sexual elements, and is, therefore, a *hermaphrodite.*

In other cœlenterates a somewhat different sequence of events is observed. Thus in the small marine hydroid polyp, known as Obelia, we find near the base of the stalk certain members somewhat resembling the polyps, but having no tentacles and containing rounded bodies of small size—the *sporosacs.* When ripe they

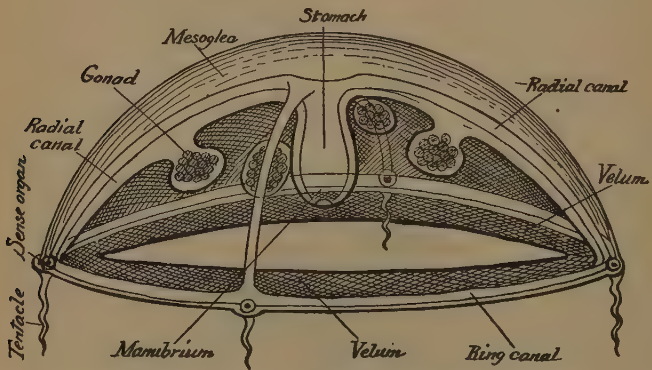


FIG. 78.—Lateral view of a medusa of Obelia. Magnified. (*Ad. nat.*) (*After Masterman.*)

rupture and permit the escape of small modified polyps, not unlike the jelly-fishes in general appearance, though extremely minute, and known as *medusæ.* They are umbrella-shaped, the opening below. From the centre there hangs a central member, known as the manubrium, upon which the mouth opens into a little bag, the cœlenteron or general digestive cavity, which communicates with four radiating canals which run to the rim of the umbrella where they connect with a ring canal, opposite to which there is a sense organ. The structure is highly specialized, as contrasted with the hydroid parents. The

medusæ are free and swim about by opening and closing the umbrella, and nourish themselves like the jelly-fishes. After a certain duration of vegetative life, *gonads*, or reproductive organs, make their appearance. These are, however, different in the different medusæ, some producing ova, others spermatozoa, so that these little animals are *diœcius*, or of two sexes. The eggs, being discharged, are fertilized by conjugation with spermatozoa in the water. From these eggs a larva is developed which swims to the bottom of the water, attaches itself to some object, and develops into a hydroid polyp. Thus, in the life history of this little animal we find two stages which alternate, one of fixed hydroid and one of free swimming medusa form. It is thus said to exhibit *metagenesis* or *alternation of generation.*

Among the sponges the sexes seem to be clearly separated so that the animals are all diœcius. The cells which take on the reproductive function are known as gonocytes and are amœboid. The spermatic cells break up into a considerable number of spermatozoa which are liberated into the water. The ova which form in some other sponge are also amœboid and force their way through the entodermal cells until they protrude into one of the inhalant canals where they await the arrival of a spermatozoon in the water. When conjugation has taken place and fertilization been effected, the ovum again draws back into the body of the sponge and shortly undergoes segmentation by the formation of a considerable number of equal-sized divisions resulting in a blastula or hollow sphere composed of one layer of cells. The cells of one hemisphere next increase in number above those of the other, and acquire flagella, after which the embryo leaves the body of its parent and swims away. Soon the non-flagellated cells, which appear granular, begin to grow and invaginate the flagellated cells so that the embryo, being no longer able to swim, settles down upon some object to which it later becomes attached. An osculum opens at the

free side, pores soon open here and there upon the surface, the internal cells throw out cilia into the paragastric cavity, and a sponge is formed.

The reproduction of the ferns is of considerable interest because these plants again show a peculiar form of conjugation effected by male and female cells of common

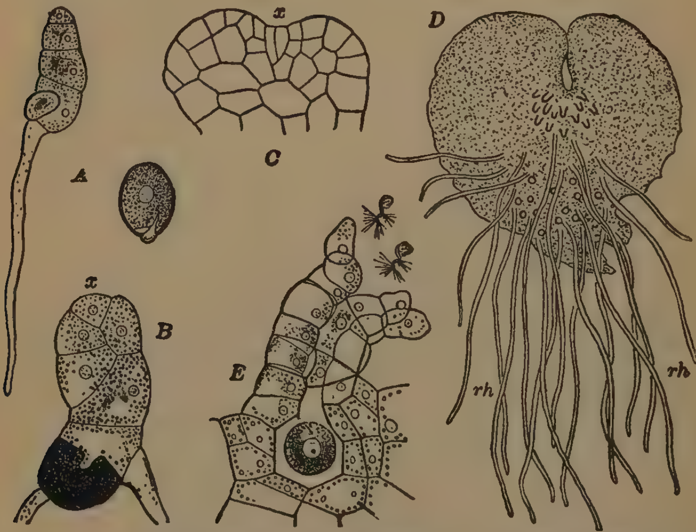


FIG. 79.—The fern prothallium and archegonium. A, Stages in the germination of the spore; B, young prothallium, showing first appearance of wedged-shaped, apical cell *x;* C, tip of prothallium beginning to take on the heart-shaped form; *x*, apical cell; D, mature prothallium, showing group of archegonia on the cushion just back of the notch, and antheridia further back; *rh*, rhizoids; E, an open archegonium with egg ready for fertilization and two sperms near the entrance of the neck. (A, B, C, E, *after Campbell;* D, *after Schenck.*) (From Bergen and Davis' "Principles of Botany." Ginn & Co., publishers.)

parentage. Thus the fern produces a large number of spores which, however, do not grow into ferns, but under favorable conditions develop into a peculiar thin, fleshy, heart-shaped mass, called the *prothallium*. This always remains small, not exceeding one or two centimeters in diameter. The greater part of it is purely vegetative,

but upon its under surface there eventually appear two groups of sexual organs, *antheridia*, constituting the male elements and producing spermatozoids; and *archegonia*, or female elements, producing each a single egg cell or ovum. Water is essential to the further progress of events, in order that the spermatozoids, which swim freely, may reach the archegonia, to which they are attracted through a chemotropic affinity, that probably depends upon the presence of malic acid in the latter. Reaching the ovum in the archegonium a spermatozoid conjugates with it, after which the fertilized ovum develops into the asexual plant or fern. Here we find an alternation of generations, the purpose of which seems to be conjugation, though how such conjugation of two cells directly traceable to a common parent can be so essential as to merit so roundabout a method for its accomplishment is difficult to imagine.

The reproduction of the higher plants shows many interesting endeavors to escape "self-fertilization" and profit by the advantages of "*cross-fertilization*," though the latter can scarcely be said to assume the importance that is seen among animals.

Thus, among the phanerogams, or flowering plants, we find many plants bearing flowers possessing male (*anthers*) and female (*pistil*) organs that mature at the same time, so that their fertilization must usually be affected by their own pollen grains dropping directly upon the stigma, growing down to the ovules in the ovary, conjugating with and fertilizing them. Indeed, in *cleistogamous* flowers, like the peas, in which the sexual organs are never exposed, it is scarcely possible for fertilization to take place in any other way. But although this is characteristic of a number of plants, so many devices are found among flowers in general, for its prevention, that it would seem as though the best interest of plant life is opposed to it. Thus the stigma and anthers of flowers do not usually mature at the same time; *i.e.*, they are subject to *protandry*, or the maturation of the an-

thers before the stigma, when the flower must be fertilized by pollen from other flowers younger than itself, or by *protogyny*, or maturation of the stigma before the anthers, when it must be fertilized by pollen from flowers older than itself. In either case, the conjugating elements must come from different flowers, though these may be upon the same plant.

In other flowers an inequality in the length and position of the stigma and anthers prevents self-pollination and consequent self-fertilization.

Some plants develop two sets of flowers, male and female, respectively, and other plants are of distinct sexes, certain individuals producing only male, and others only female flowers.

In a few cases the pollen from a flower when dropped upon the stigma of the same flower fails to grow into the usual filaments, or, doing so and descending to the egg cell, fails to conjoin and fertilize it, or does so only when no pollen from a different flower finds its way to the same stigma. In some cases, when pollen from the same flower and from a different flower arrive at the same time, upon the same stigma, the exogenous pollen appears to outgrow the autogenous pollen and more quickly finds its way to the egg cells and effects fertilization. It is probably by this means that cross-fertilization is effected in those cases in which the pollen from various flowers with sexual organs maturing at the same time is freely distributed by the wind. The same means of securing the advantage of cross-fertilization is probably adopted in those cases in which the flowers are *entomophilous* and visited by insects that not only sprinkle pollen belonging to the flower upon its stigma, but also bring it pollen from other and remote flowers.

Thus the phaneroganic vegetation displays a pronounced disposition to secure cross-fertilization, though its importance seems to vary widely in different cases.

The animal kingdom, however, shows a much more restricted sexual development. *Hermaphroditism*, or the

occurrence of both sexes in the same individual, is almost as much the exception in the animal world as it is the rule in the vegetable world. It might be reasonable

FIG. 80.—Withdrawal and deposition of pollinia in the flowers of an orchid. Flowering spike of the broad-leaved helleborine (*Epipactis latifolia*) upon which a wasp (*Vespa austriaca*) is alighting. 2, A flower of the same seen from the front; 3, side view of the same flower with the half of the perianth toward the observer cut away; 4, the two pollinia joined by the sticky rostellum; 5, the same flower being visited by a wasp, which is licking honey and at the same time detaching with its forehead the tip of the rostellum together with the pair of pollinia; 6, the wasp leaving the flower with the pollinia cemented to its head, the pollinia are erect; 7, the wasp visiting another flower and pressing its forehead with the pollinia (which in the meantime have bent down) against the stigma. (*Kerner and Oliver.*)

to regard this difference as referable to the prevailing restriction of movement among plants, as contrasted with the freedom of movement among animals, making it correspondingly difficult or easy for different individuals

to reach one another for reproductive purposes. And we see among the hermaphrodite animals the same repugnance to self-fertilization where it is not made essential by the peculiar conditions of life. Thus of hermaphroditic animals we find self-fertilization practised by the parasitic worms whose existence is so precarious that it is exceptional to find more than one in the same host, but not among the earthworms or snails that are free and independent.

The higher we ascend in the animal kingdom, the more emphatic is the demand for conjugation of gametes from separate individuals of opposite sexes. Not only does sexual differentiation take place low down in the scale of life, but the ability of the gametes of sexual cells to undergo *parthenogenetic* development, or to develop without fertilization, also quickly disappears, not being observed among animals higher than the arthropods. Development by gemmation also disappears very early, so that there is nothing in the higher animal organisms that is in the least degree comparable to the multiplication by budding so prevalent among the higher plants. Reproduction among animals, therefore, soon narrows itself down to the formation of gametes, produced by sexually different indviduals, the conjugation of these gametes and the formation of a zygote or fertilized cell which grows into an embryo, which after certain metamorphoses develops into a sexual individual resembling one or the other parent.

There is an early differentiation of the cells of animals into those known as *somatic*, of which the body proper consists, and those known as *germinal* whose office is solely reproductive. The latter are contained in the *gonads* or sexual organs until the organism to which they belong becomes sexually mature, when they themselves undergo certain essential changes preparative to the fertilization that initiates the reproductive process.

In vegetables it cannot be shown that the germinal cells differ essentially from the somatic cells. They

PLATE I

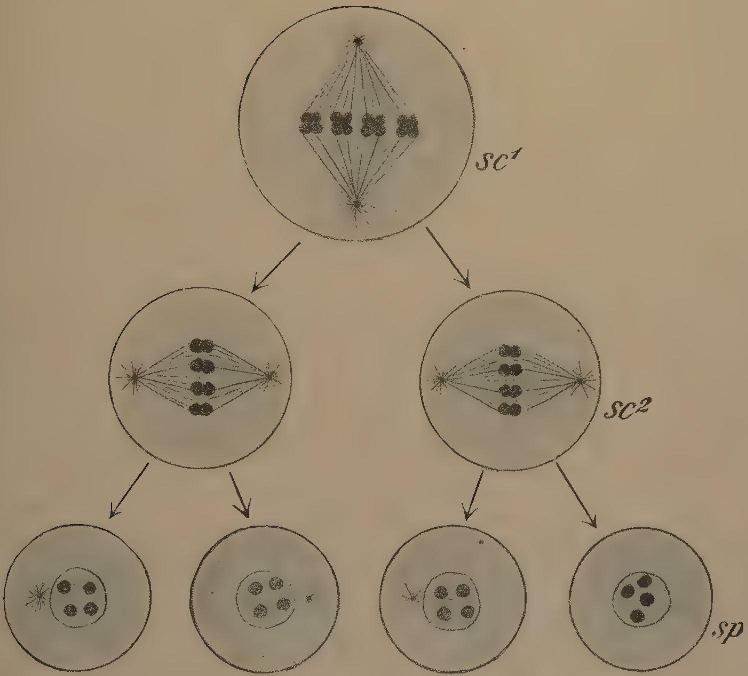


Diagram illustrating the reduction of the chromosomes during spermatogenesis: sc^1, Spermatocyte of the first order; sc^2, spermatocyte of the second order; *sp*, spermatid (*McMurrich*).

appear only when the reproductive process is anticipated, attain to the necessary degree of specialization in a few generations, are characterized by a preparation for fertilization to all intents and purposes identical with that of the animal cells, and then having been fertilized by conjugation with another specially adapted cell, lose the reproductive quality and become vegetative in character once more. Thus, in vegetables the reproductive activity may be said to pervade the cells generally, while in animals it is more and more restricted to the few cells comprising the *germ plasm.*

It is of the utmost importance that the steps preliminary to sexual fertilization be carefully followed, and for this purpose it will be necessary once more to enter the domain of cytology.

Among both plants and animals the germinal differ from the somatic cells in possessing twice the number of chromosomes. Yet the gametes contain but half as many. This depends upon a "*reduction of chromosomes*" seen in the maturation of the germinal cells. It is a matter of much interest, and as it has fundamental bearing upon the problems of inheritance and variation, some attention must be devoted to the histogenesis of the gametes.

Any of the higher plants or animals will be found to possess specialized germinal cells set aside in the gonads or sex organs until sexual maturity awakes them to activity. As there are two sexes, and the sex organs and their products differ, two kinds of gametes, the male, or *spermatozoa*, and the female, or *ova*, are to be studied, and two subjects, *spermatogenesis* and *oogenesis*, appear for investigation.

Spermatogenesis.—The germinal cells early set aside in the animal gonads are few and therefore undergo great increase in number through karyokinetic division before enough shall have been formed to supply the requirements of sexual life. Even during the period of sexual activity multiplication of these cells may be required

and may progress by the usual mode of cell division, and no other difference between dividing germinal cells and dividing somatic cells can be detected than is indicated by the number of chromosomes which is twice as great in the germinal as in the somatic cells. During this time the chromosomes are filamentous in appearance, and the division of a cell results in the passage into each half of an equal quantity of chromatin. In this manner complete quantitative and qualitative uniformity of the germinal cells is maintained.

When the time for the maturation of the spermatocyte has arrived, a change in the shape and appearance of the chromosomes is observed. Instead of maintaining their filamentous character, they now become globular and peculiarly arranged. Thus, supposing the somatic cells of the organism under study to be provided with sixteen filamentous chromosomes, as in man, we find the spermatocytes at this stage furnished with thirty-two, of spherical shape, peculiarly grouped into eight *tetrads*.

This new arrangement of things having been effected, the cell, which is known as a *primary spermatocyte*, divides into two in such manner that each tetrad divides into two *dyads* and each resulting cell possesses sixteen chromosomes in pairs or dyads. This is no sooner ended than each cell or *secondary spermatocyte* prepares for another division without other nuclear change than an alteration in the position of the dyads, each of which separates into two *monads*, so that each of the four cells finally descending from the primary spermatocyte is provided with but eight chromosomes of spherical shape. These cells are the future spermatozoids, whose further morphological transformations have nothing to do with the chromosomes and need not further concern us at present.

Oogenesis.—This process corresponds with spermatogenesis with the single exception that, instead of resulting in four similar and functionally active cells, it usually terminates in four cells, of which one is functional and

PLATE 2

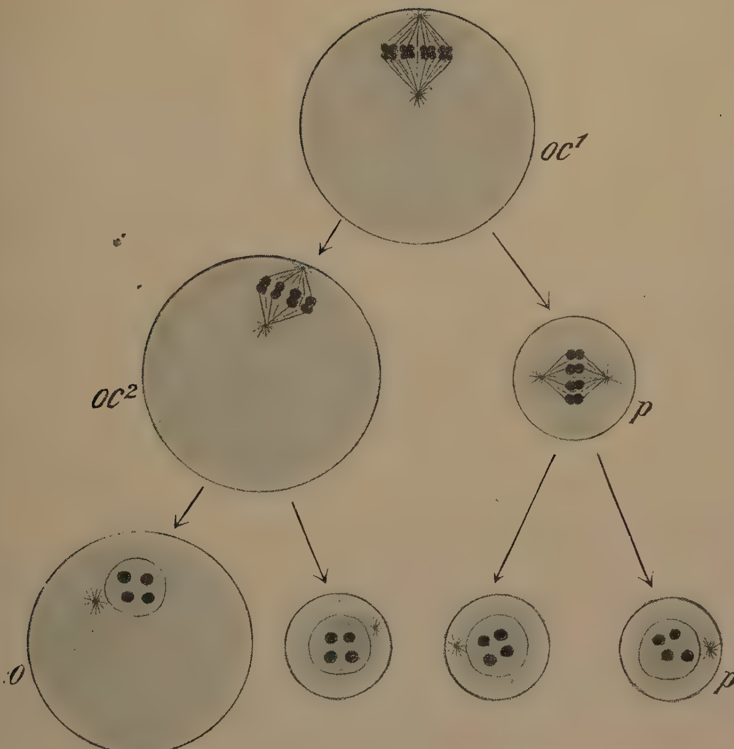


Diagram illustrating the reduction of the chromosomes during the maturation of the ovum: *o*, Ovum; *oc*[1], oöcyte of the first generation; *oc*[2], oöcyte of the second generation; *p*, polar globule (*McMurrich*).

three abortive. A minor difference, not to be neglected, is that in spermatogenesis the whole transformation is completed in the spermatogonium (*testis* in animals), whereas in the oocyte much of it takes place after it leaves the oogonium (ovary), and sometimes after the conjugation process has begun.

Like the human spermatocyte, the human oocyte contains thirty-two chromosomes which are at first filamentous, but which become globular and collected into tetrads as the time of maturation arrives. Like the spermatocyte, the oocyte also undergoes two successive divisions for the purpose of reducing its chromosomes. During these divisions, which are equal in size and importance as regards the nuclear substance, but very unequal as regards the cytoplasm, the nucleus moves to the extreme periphery of the cell, so that the completion of each nuclear division results in the formation of what appears to be a bud upon its surface.

In the first reduction division the tetrad chromosome formations become divided transversely so that an equal number of *dyads* pass out into the tiny cell and remain in the mother cell. Each has now sixteen chromosomes of dyad shape. After a brief interval the process of division is repeated both by mother and daughter cells, so that eventually there are four cells, each with eight chromosomes of monad or globular form.

Among the higher animals the ovum alone persists for conjugation and development, the smaller cells resulting from the reduction division, and known as "*polar bodies,*" disappear as far as present knowledge goes.

The purpose of reducing the chromosomes in this manner seems to be the admission to the zygocyte of an equal quantity of essential substance (chromosomes) from each parent, a matter the importance of which will be better understood when the subject of conformity to type has been discussed.

The nucleus of the spermatozoon with its reduced number of chromosomes is known as the *male pronucleus;*

that of the ovum with its reduced number of chromosomes as the *female pronucleus.*

Fertilization is effected by the entrance of the male pronucleus into the female cell whose nucleus appears to advance to meet it. Coming together near one pole of the cell, the two pronuclei conjugate, mingle their chromosomes, and so form a new nucleus for the zygote or fertilized cell which thus comes into possession of the full somatic number of chromosomes.

The process of chromosome reduction generally pervades the world of multicellular living beings. Related phenomena also make their appearance among unicellular organisms.

Many interesting examples of the special means by which reduction of chromosomes is effected among plants might be given, but at an expense of space that would scarcely be worth while in a writing not particularly devoted to plant physiology. In dismissing the subject, however, one fact should be mentioned, that is, that among the ferns, mosses, and algæ, where alternation of generations exists, the asexual generations (sphorophytes) have spores possessing the somatic number of chromosomes, while the sexual generations (gametophytes) produce sexual cells, or gametes, having the reduced number.

This fertilized cell or zygote is immediately ready for development into the new individual, which through the receipt of an equal number of chromosomes from each parent inherits characteristics from each. The development of the zygote into the new individual forms a new phase for study known as *ontogenesis.*

References.

Same as for Chapter VII.

CHAPTER IX.

ONTOGENESIS.

Every living thing begins its existence as a single cell, a condition of primitive simplicity, and finally arrives at a varying degree of complexity, according to its phylogeny. The study of the intervening transformations through which each organism must pass is known as *ontogenesis* or *ontogeny*. During the early stages of development, there is no resemblance between the parent organism and the growing germ which is known as an *embryo*. The study of embryos and their development is called *embryology*.

When the embryo of one of the higher animals reaches a certain point, and has developed sufficiently to enable its specific characters to be recognized, it becomes known as a *fœtus*.

If, as in certain cases, the embryo becomes self-sustaining and independent, without attaining parental resemblance and continues for some time in this "semi-developed" form, it is described as a *larva*.

The early writers upon the science of development, having no data upon which to build, were obliged to content themselves with theoretical speculations, most of which are of little interest to-day, yet they deserve consideration and are useful as exemplifying how wide of the truth theory may lead and how difficult it may be for it to give place to fact.

Until the time of William Harvey (1578–1657) the whole subject of "generation" was so obscure as to merit scant attention. He took up the subject from the experimental side and brought it to the point from which

no departure has since been possible, namely, that "the egg is the common beginning of all animals" (*Ovum esse primordium commune omnibus animalibus*). The discovery of the spermatozoon was made in 1677 by Hammen. He showed these little bodies to Leeuwenhoek, who studied them with enthusiasm and diverted further attention from being bestowed upon the egg by declaring the spermatozoa to be the essential germs and that in them were present the beginnings of the future soul. It was even believed that they were minute living animals of both sexes, capable of coition, etc., and the philosopher Leibnitz declared them immortal. Scientists and philosophers soon became divided into two schools, the Ovists and the Animalculists. As the ideas of the *Animalculists* departed so far from the truth as to find no place in modern thought, they can be dismissed with the remark that, following Plantade (1699), they eventually came to see in the human spermatozoon a complete miniature of the human fœtus, enclosed in its membranes, its head bowed upon its breast, and its limbs flexed—the "*homonculus*"—and supposed that when such an entity was properly received by the uterus it proceeded to grow into a human being.

The *Ovists*, on the other hand, regarded the spermatozoon with comparative indifference. Some believed it to be a parasitic animalcule of the semen, others conceived that it carried some stimulating force by which the growth of the egg was stimulated. They all agreed that it was in the ovum that the future being was contained. The ideas of the philosophically minded of this school eventually crystallized into the "*preformation theory*," or "*theory of evolution*," by which it was supposed that the ovum of every animal contained a miniature of the future adult, complete in every detail, and only requiring nourishment in order that it should grow larger and larger until the adult size was reached. "There is no such thing as becoming," is the way it is expressed by Haller in the "Elements of Physiology;"

"No part in the animal was formed before another: all were created at the same time." "Against such contradictory evidence as the metamorphoses of insects, the preformationists had none but verbal weapons and dogmatic opinions that found expression in the statement that though it might not be in a visible form, still the caterpillar contained in itself the pupa, and the pupa the butterfly, therefore the butterfly was already present, as such, in the caterpillar."

Successive generations were accounted for by supposing that the human ovary not only contained numbers of ova, each containing an individual in miniature, but that in the ovary of this minature there were many other and smaller miniatures, and within these still others, and so on, like the Japanese nests of boxes, one within another. "In the extension of this *box-within-box* doctrine (Einschachtelungslehre) the distinguished physiologist, Haller, calculated that God had created together, 6000 years ago—on the sixth day of his creatorial labors—the germs of 200,000,000,000 men, and ingeniously packed them all in the ovary of our venerable mother Eve." This was, of course, all theory, but there seemed to be no disposition to get at the true facts. The theory of *epigenesis*, or development of the embryo, taught by Hippocrates and Aristotle, was almost forgotten, until Caspar Frederich Wolff (1735–1794) again brought it into prominence by studies of the developing hen's egg, in which he found no preformed individual, but one growing, transforming, and differentiating in a manner easy of study and demonstration. In his doctor's dissertation (1759) Wolff laid down the scientific principle that what one could not recognize by means of the senses was certainly not present preformed in the germ. "At the beginning," so he maintained, "the germ is nothing else than an unorganized material eliminated from the sexual organs of the parent, which gradually becomes organized, but only during the process of development, in consequence of fertilization."

So strong, however, were the preformationists that Wolff failed to make much impression and, although a simple investigation might have satisfied any scientific observer of error, the real revival of *epigenesis* was deferred for nearly a century—until 1827, when Carl Ernst von Baer discovered the mammalian ovum.

It is difficult to trace the early discoveries appertaining to fertilization. The fact that it is necessary for the ovum to contact with the seminal fluid in order that fecundation may take place seems to date from the time of Swammerdan (died 1685); that the spermatozoa were inseparably connected with it from the time of Hartsoeker (1665–1725). The observation that the spermatozoon of the rabbit actually entered the ovum was first made by Barry. The first to trace the development of all the tissues from the primordial germinal cells to the stage of complete evolution seems to have been Theodore Schwann (1839).

The starting point of embryological development, as seen in the light of present scientific knowledge, has been reached in the chapter upon Reproduction where the germinal cells, early set aside in the gonads, or reproductive organs, maturing as gametes, pass through the period of maturation characterized by the chromosome reduction. Following this comes the conjugation process known as fertilization, by which the zygote or fertilized cell receives an equal quantity of essential nuclear (chromosome) substance from each gamete, and therefore from each parent of the individual about to be formed.

It has already been pointed out that the ovum, not being motile, is in a certain sense passive; the spermatozoon, which is motile, active in the process. The spermatozoon is no doubt attracted to the ovum by that elementary characteristic of protoplasm already described as chemotropism.

The fertilization is differently effected according to the differing conditions of life. Thus, when the animals are aquatic, the ova and spermatozoa may be discharged

into the surrounding water and their conjugation trusted to chance. When they are terrestrial, special means must be taken to overcome the obstacles of gravity, etc., and means provided for conveying the spermatozoa to the ova. Many means used by plants for effecting fertilization have already been discussed. Terrestrial animals are usually furnished with sexual organs fitted for coitus so that the sperm of the male may be directly introduced into the organs of the female where fertilization takes place.

In plants the external, in animals the internal, morphological characters predominate in importance. This occasions certain fundamental differences in embryology by which the development of the plants becomes a separate subject, to describe which would, on account of the diversified forms to be considered, divert us from the general scope of this writing. It must, therefore, be left to those intending to pursue botany as a specialty, and be dismissed with the brief statement that it conforms to the general principle that embryological development is the passage of the organism from the simplicity of unicellular structure to the complexity of differentiated multicellular structure, and that in this transformation the embryo passes through a series of stages which suggest the phylogenetic ascent of its kind. The significance of this expression will be better understood after the perusal of the matter that is to follow.

Every metazoan begins its life history as a single cell or egg, and whether this is a distinctly differentiated germinal cell or egg or an indistinctly differentiated germinal cell such as forms the starting point of the gemmation of cœlenterates, etc., makes no essential difference.

For the present, however, we shall neglect the undifferentiated and consider only the differentiated germinal cells—the true eggs.

These present a great variety of appearances, but little difference of structure, as each is a single cell. They

vary from a size so small as to be microscopic to several pounds in weight (ostrich egg), may be naked and purely protoplasmic or covered with membranous, leathery, or calcareous encasements, these differences serving to enable even a beginner to realize that there are phylogenetic differences even among the eggs themselves. No doubt, increasing familiarity with eggs in general will eventually show that the differences are not only such as to enable eggs to be referred their respective phyla, but to their respective classes, orders, genera, and even species, as can readily be done at present, for example, with birds' eggs and many insects' eggs.

Not only are there such external differences, but there are also striking internal differences among eggs, which not only assist in their classification, but also assist in explaining peculiarities attending their development.

Thus, a superficial examination enables one to separate eggs into those that are *holoblastic*, or without yolks, and those that are *meroblastic* and have yolks, and to discover that though the eggs differ in size, as do the other cells of the respective animals to which they belong, the presence or absence of a yolk and the size of that yolk have much to do with the size of the egg. The yolk is, moreover, inclosed in the egg, which, according to its size, is surrounded by a thicker or thinner protoplasmic envelope. The yolk which is composed of deuteroplasm is intended to nourish the developing embryo, hence the magnitude of the yolk must bear some reference to the dependence of the embryo upon that form of nourishment. In cases in which the egg is quickly developed into a self-sustaining larva, there is no yolk; in cases where it becomes attached to the uterine wall of the parent from whom it derives nourishment, the yolk may be inconspicuous, but in those cases —the birds, reptiles, fishes—where the egg is entirely separated from the parent and completes its embryonal transformations without a larval form in which additional nourishment can be secured from without, the

yolk must be large enough to supply all of the embryonal requirements.

The encumbrance of the yolk modifies the earliest transformations of the egg—cleavage—as will be shown.

Before leaving the eggs it is necessary to give brief attention to the subject of fertilization. When an egg is surrounded by a leathery or calcareous covering before expulsion from the maternal body, it cannot be subsequently fertilized, so that in such cases the spermatozoa must have been emitted into the maternal organs, where they meet and fertilize the egg before its final coverings are provided, unless such coverings contain one or more openings—micropylæ—for the special purpose of admitting the spermatozoa.

The developmental process begins by cell division, "*cleavage,*" or "*segmentation*" of the ovum, which is followed by that cellular multiplication through the continuance of which the different tissues and organs are produced.

The mode of segmentation differs in different eggs, partly through peculiarities of the eggs, partly through inherited impulses inherent in them. Hertwig presents the following scheme of cleavage:

I. Type.—Holoblastic eggs (without yolks).
Total cleavage: a. Equal cleavage lower invertebrates and mammals). b. Unequal cleavage (mollusks and amphibia).

II. Type.—Meroblastic eggs (with yolks).
Partial cleavage: a. Discoidal cleavage (fishes, birds, and reptiles). b. Superficial cleavage (insects and arthropods).

Thus it is at once apparent that the presence or absence of a considerable yolk determines whether the cleavage shall be total or partial, and the examination of any thorough description of the development of the chick will make clear the manner in which the enormous yolk modifies segmentation.

So soon as segmentation has begun it is possible to recognize a *chief* or *primary* axis and to differentiate an *animal pole* and a *vegetative pole.* Those cells that arise in the neighborhood of the animal pole give rise to the *ectoderm* from which the integument, the nervous system, the glands; the organs of special sense, etc., develop, which, so to speak, preside over the animal function. Those from the opposite pole comprise the cells of the *entoderm,* from which arise the digestive and reproductive organs which preside over the vegetative functions.

This chief axis may be recognized, in large meroblastic eggs, even before development begins, and in many cases is distinct as soon as it begins; thus, in the hen's egg, the germinal vesicle represents the animal pole, the great opposed mass of the yolk the opposite or vegetative pole.

All of the metazoa early show a monaxial, heteropolar condition about which the developmental process centres. In eggs with yolks the animal cells are lighter than the vegetative cells, so that the animal pole always turns up, no matter in what position the egg is placed. In eggs without yolks and with equal or fairly equal cleavage the animal cells distribute over the surface and the vegetative cells arise within, so that the vegetative pole is central.

The process of cleavage takes place through karyokinesis, the plane of division being perpendicular to the long axis of the spindle. Two cells are thus produced, each of which appear to possess an equal amount of reproductive energy and an equality of all the factors concerned in development, for it has been found by experiment that if these halves can be separated and the developmental process continued, as is possible with some of the lower animals, each is able to progress without apparent serious disturbance to complete development.

Further cleavage results through further karyokinesis,

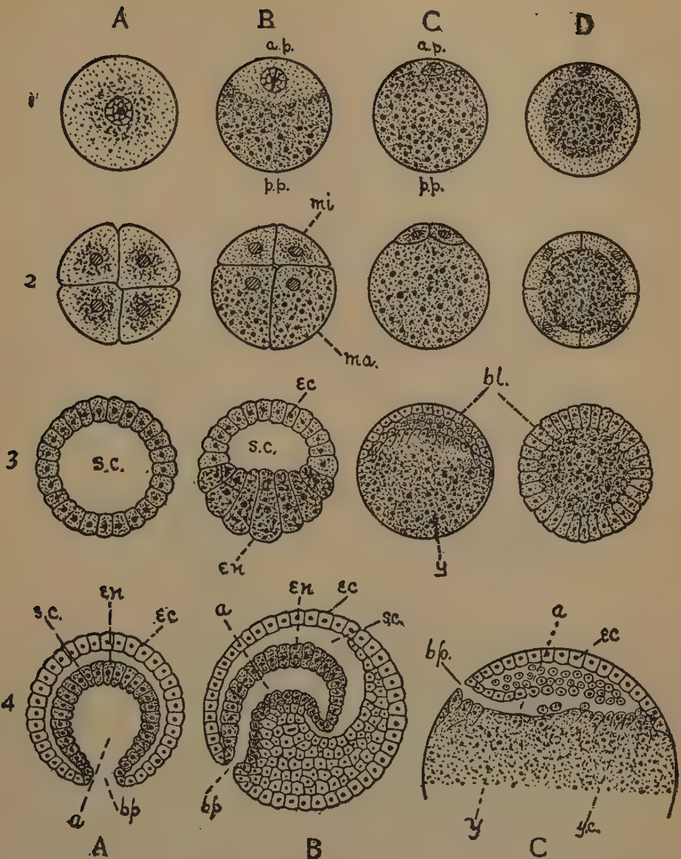


FIG. 81.—Cleavage and gastrulation (not drawn to scale). The vertical rows A, B, C, and D represent different classes of ova. A, an ovum with little yolk; B, one with considerable yolk collected at the lower pole (*p.p*); C, one with a large amount of dense yolk crowding the protoplasm to one side (*a.p*); D, ovum with dense yolk collected at center. The numerals (1–4) indicate stages in cleavage and gastrulation: 1, ova; 2, 4–8 celled stages of segmentation; 3, blastospheres, blastula stage; 4, gastrula stage. *a*, Archenteron; *a.p*, active pole; *bl*, blastoderm; *bp*, *ec*, ectoderm; *en*, entoderm; *ma*, macrospheres; *mi*, microspheres; *p.p*, passive pole; *s.c*, segmentation cavity; *y*, yolk; *y.c*, yolk cells. (*Galloway.*)

the poles of the nuclear spindle always being directed toward the greatest protoplasmic masses, so that there result four, eight, sixteen, thirty-two, sixty-four, 128 cells, or *blastomeres*, and so on. This process of cleavage, though taking place after karyokinetic changes, differs from ordinary cell division in that it progresses so rapidly that no time is allowed for growth and the cells become smaller and smaller as they divide.

In equal cleavage the cells of the two poles are of uniform size; in unequal cleavage their number is the same, but the size varies, the animal cells being smaller than the vegetative cells. Equality of numbers is not, however, preserved, for either the richness of protoplasm in the animal half or the magnitude of the cells of the vegetative half determines that the former outgrows

SECTION OF MORULA.

SECTION OF BLASTULA.

FIG. 82.—Section of morula. (*Masterman.*)
FIG. 83.—Section of blastula. (*Masterman.*)

the latter until with 128 cells in the animal half there may be but thirty-two in the vegetative half, and so on.

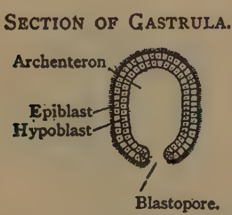
The inequality of the cleavage is in direct proportion to the quantity of yolk at the vegetative pole. Thus, in holoblastic eggs, the cleavage may be equal; in the enormous meroblastic eggs of birds the yolkless protoplasm assembled at the animal pole is alone able to undergo segmentation, and the primitive assemblage of cells resulting from this localized cleavage appears as a cellular disc floating upon the surface of the yolk. This *germinal disc* receives the name "*blastoderm.*"

The segmentation first results in the formation of a solid cellular mass which bears a partial resemblance to a mulberry and is known as a *morula*. Every egg passes through this stage. Soon, however, the morula

becomes changed by assumption of fluid or by vacuolization of the inner cells, and a hollow sphere is formed, the *blastula,* surrounded on all sides by a single layer of blastomeres.

The eggs of the invertebrates always form blastulæ, some of which are ciliated, free-swimming, and self-sustaining larval forms. Such are called *monoblastic larva.* They are typically centro-symmetric, the hollow centre being known as the *archicele* or *blastocele,* the cellular layer as the *archiblast.* The sponges have larvæ of this form.

Holoblastic eggs of higher animals, having formed a blastula, next undergo a peculiar invagination through



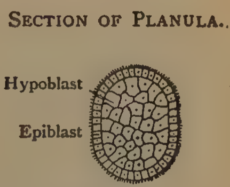


FIG. 84.—Section of gastrula. (*Masterman.*)
FIG. 85.—Section of planula. (*Masterman.*)

the ascent of the vegetative pole of the blastula layer, until it comes into contact with the cells of the animal pole. The invaginated blastula thus comes to resemble a hollow ball one side of which has been pressed in against the other. The result of the invagination is that the embryo now consists of a double layer of cells, surrounding a new cavity formed by the invagination, while the original segmentation cavity has virtually been extinguished. The embryo is now called a *gastrula,* and is *diploblastic,* because it consists of an outer layer of cells, the *ectoderm* or *epiblast,* and an inner layer, the *entoderm* or *hypoblast.* The cavity formed by the invagination is now known as the *archenteron,* and becomes more and more enclosed by increase in the

cellular layers until the original bell-shape gives place to a more spheroidal form with a central opening, the *blastopore.*

Embryos at this stage bear a distinct resemblance to certain larvæ of cœlenterates, and indeed this diploblastic larva is the general plan of development, as well as the foundation of structure of the medusæ.

Holoblastic eggs of still higher animals next progress to the formation of *triploblastic* larvæ through the formation of a third cellular layer, the *mesoblast,* which arises from two rudiments symmetrically arranged on opposite sides of the central axis. In different embryos its

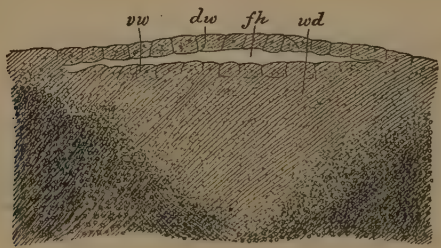


Fig. 86.—Section through the germ disc of a freshly laid unfertilized hen's egg. *fh,* cleavage-cavity; *wd,* white yolk; *vw,* lower cell layer; *dw,* upper cell layer of the blastula. (*After Duval.*)

appearance and arrangement vary, but it is described by Masterman thus: "It consists of a more or less complex double layer of cells of which the outer layer lines the epiblast and the inner covers the hypoblast. These two layers enclose a spacious cavity, called the *cœlum,* which is usually filled with a nutrient fluid. The cœlum is not usually continuous, but it may be divided in the median plane by dorsal and ventral mesenteries, which are double and serve to support the hypoblastic canal; or it may be divided up by lateral mesenteries or septa running transversely to the long axis of the organism. The mesoblastic walls later form the muscles, skeletal

tissues, gonads, and partly the excretory organs; and the cœlum often communicates with the exterior by paired canals called nephridia."

An embryo arrived at this degree of complexity will be found to conform fairly well in structure with that of the unsegmented worms, though it may not otherwise resemble them.

If we now digress to see how the early development of meroblastic differs from that of holoblastic eggs, we find the dissimilarities chiefly accounted for by the presence of the yolk. When this is large, as in the hen's egg, it is impossible for blastulation and gastrulation to take place in the manner described. Instead, the segmenta-

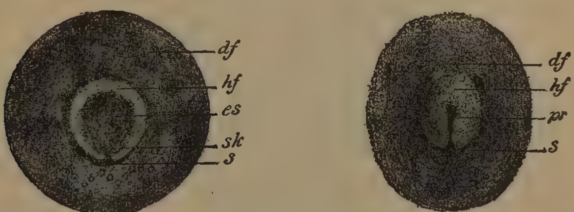


Fig. 87.—Two germ discs of hen's egg in the first hours of incubation. *df*, Area opaca; *hf*, area pellucida; *s*, crescent; *sk*, crescent-knob; *es*, embryonic shield; *pr*, primitive groove. (*After Koller.*)

tion is partial (discoidal) and limited to a superficial area where it forms a "germinal disc" or group of cells which, so to speak, floats upon the upper surface of the egg. This germinal disc after developing to a certain point undergoes differentiation into a superficial layer and deeper layers which are separated by a narrow interval or space, which constitutes the cleavage cavity. Thus, through a modification necessitated by circumstances, the homologue of the blastula is produced. As the blastula is perfected, gastrulation takes place not by the simple invagination of one side of the sphere, for the segmentation cavity is not spherical, but through a combination of folding and invagination by which one

portion, the outer layer, forming an ectoderm, comes to overlie the inner layer, the entoderm, and form a kind of blind sac, the slit-like opening into which is the blastopore.

If at this time the egg of the hen could be observed from the external surface over the germinal disc, one

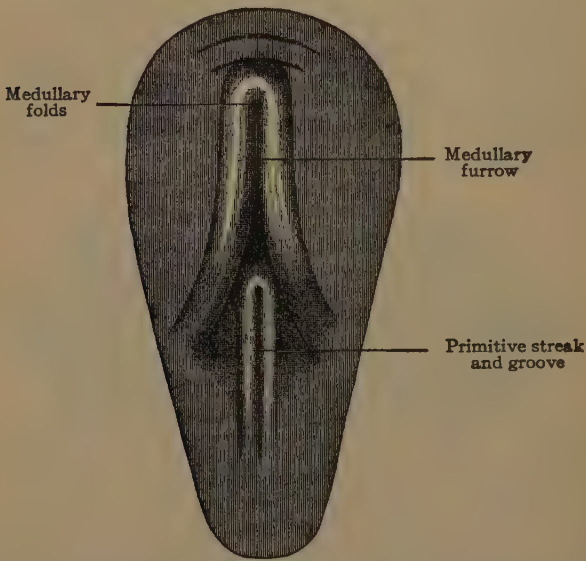


FIG. 88.—Surface view of area pellucida of an eighteen-hour chick embryo. The area opaca is omitted; the pear-shaped outline marks the limit of the area pellucida. At the place where the two medullary folds are continuous with each other there is to be seen a short curved line, which represents the head fold. In front of it there lies a second line concentric with it, the beginning of the amniotic fold. (*Balfour.*)

would see an oval area undermined posteriorly. At the centre of the posterior flap a little notch soon makes its appearance, which becomes deeper and ends in a groove extending anteriorly half the length of the disc—the *primitive groove*—in the centre of which is a linear marking, the *primitive streak.*

The primitive embryo thus comes to consist of two germinal layers, ectoderm and entoderm, forming a concavo-convex plate, the convex surface of which consisting of ectoderm is destined to form the dorsum and external coverings of the embryo, the concave surface the internal organs about which the embryo is to grow. As the growth proceeds the circumference of the germinal disc increases and the subjacent yolk is absorbed as it furnishes the growing cells with nourishment. The increasing disc does not grow uniformly and hence becomes thrown into folds which, when viewed from the dorsal surface, indicate the position of future structures. Thus an anterior transverse fold indicates where the amniotic membrane is to form; a second transverse fold,

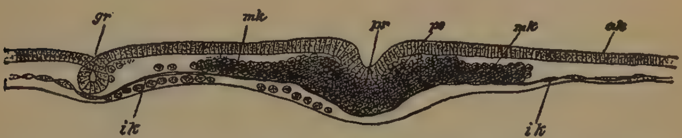


FIG. 89.—Cross-section through the middle of the primitive streak of a chick's germ disc. At some distance from the primitive groove is to be seen upon the left side of the figure in cross-section the marginal groove of His; upon the right side it is as yet little developed. *ak*, Outer, *ik*, inner, *mk*, middle germ layers; *pr*, primitive groove; *ps*, primitive streak; *gr*, marginal groove. (*After Koller.*)

where the head of the embryo is to develop. The longitudinal groove in the anterior part of the disc indicates where the spinal cord will form, and the folds on each side of the groove two arches of the ectoderm by concrescence or fusion, of which the spinal canal will eventually be formed.

While these wrinkles or folds are preparing the way for future development, the *mesoderm*, from which the skeletal, motor, circulatory, and connective tissues are to form, is being prepared by the penetration into the space between the ectoderm and entoderm of a mass of small cells in many superimposed layers, arising from both ectoderm and entoderm, and as these cells become inclosed between the two chief blastodermic layers they

also become separated from the parent blastodermic layers and differentiated as a third blastodermic layer.

A transverse section of the germinal disc at the time of the formation of the mesoderm, which coincides fairly well with the period of the formation of the primitive streak and groove, is shown in the illustration.

The future development of such meroblastic eggs depends upon their character. If the eggs are enclosed in shells, development is complicated by the formation

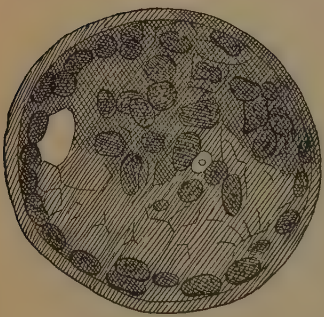


FIG. 90.

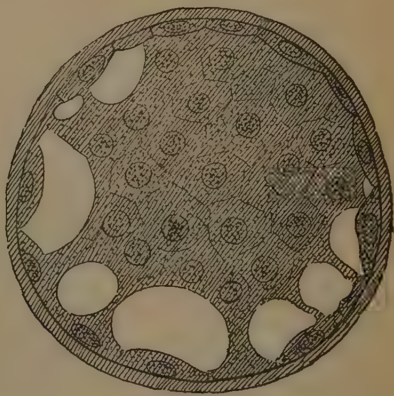


FIG. 91.

FIG. 90.—Ovum of the bat, showing vacuolation of the segmented egg to form the blastodermic cavity. × 500. (*Van Beneden.*)

FIG. 91.—Ovum of the bat, showing vacuolation of the segmented egg to form the blastodermic cavity. × 600. (*Van Beneden.*)

of a membrane investing the embryo—the amnion; if the eggs are without shells, as those of fishes, there are no membranes, and development is less complicated. In both cases the growth of the embryo continues by folding, convergence, and concrescence of the cellular germinal plate, more and more completely separating the embryo from its yolk.

Now, leaving the meroblastic eggs of the fishes, reptiles, birds, and the lowest mammals, we return once more to holoblastic eggs as we find them in mammals.

These begin development by an almost equal segmentation resulting in the formation of a morula, composed of cells of fairly uniform size. When the morula stage has been completed, vacuoles begin to appear in some of the central cells, become larger, coalesce, and give origin to an irregular fissure-like space which is the

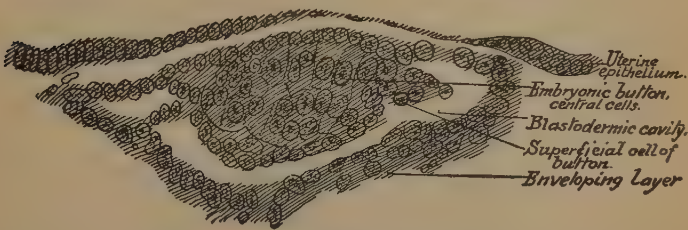


FIG. 92.—Ovum of bat; differentiation of embryonic button. (*Van Beneden.*)

segmentation cavity, or *lecithocele*, and brings the ovum to the stage of the *blastodermic vesicle.* Though not formed in a manner identical with the regular blastulæ of the invertebrates, the blastodermic vesicle is easily homologized with it and subserves the same purpose as the blastula in the subsequent developmental stages.

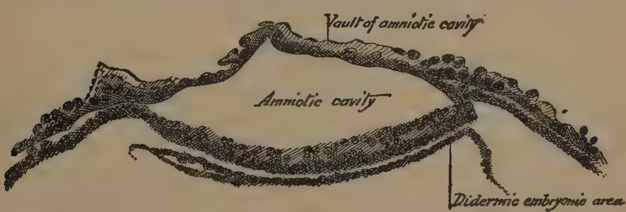


FIG. 93.—Ovum of bat, showing amniotic cavity. × 200. (*Van Beneden.*)

The mammalian ovum at this stage consists of a layer of flattened cells, the "outer cell mass," surrounding a cavity, into which an irregular mass of cells of more spherical form, "the inner cell mass," hangs suspended from one side encroaching upon the space. This embryo is imbedded in the uterine epithelium

which apparently melts away below its attachment in order that placentation may be made possible later on.

A free ovum in water or an ovum inclosed within a shell is able to perfect its differentiations undisturbed by contact with external bodies; but a mammalian ovum of small size, without a nutrient yolk to feed upon and situated in a crypt of the uterine mucosa, is obliged to prepare for its future nutrition by effecting a communication with the maternal supply, and arrange for its freedom from external interference by surrounding itself with smooth membranes within which development may proceed.

Fish embryos are without such membranes; the

FIG. 94.—Ovum of bat; differentiation of amniotic cavity. × 275. (*Van Beneden.*)

chick forms one of them, the amnion; the mammalian ovum forms two, the amnion for protection and the chorion for nutrition. It is not necessary to particularize in regard to the amnion or other fœtal membranes as this chapter is not intended to be an adequate description of the developmental details, but simply to epitomize such facts appertaining to development as shall show the harmony existing between all forms of life in the general plan upon which ontogeny is perfected.

With the formation of the amnion, the embryo advances to the point where it consists of a didermic plate, on the uterine side of which the primitive amniotic cavity is situated, on the other side of which is the yolk sac found.

This didermic plate, consisting of ectoderm and entoderm, between which the cells of the mesoderm soon make their appearance, is not essentially different from the oval germinal disc floating upon the great yolk of the hen's egg, and its future development progresses in much the same way. In the mammalian egg, however, the researches of Peters and van Beneden indicate that endoderm formation does not take place through gas-

Fig. 95.—Section through embryonic region of ovum. First week of pregnancy. *E.Sch*, Embryonic epiblast; *Ent*, embryonic hypoblast; *Mes*, embryonic mesoblast; *D.S*, umbilical vesicle; *Ekt*, chorionic epiblast; *Sp*, fold in exocœlom; *A.H*, amniotic cavity lined by a single layer of flattened cells, which are in striking contrast with the layer of cylindric cells of the embryonic epiblast. (*H. Peters.*)

trulation or invagination as in the eggs of the lower phyla, but, like the amnion formation, is arrived at by a short cut—*i.e.*, by vacuolization of certain cells.

After the formation of the embryonic area (germ disc) composed of its three germinal layers, the future developmental process consists in a succession of wrinkles and puckers resulting from unequal growth of cells in different locations, a general tendency of the external convex

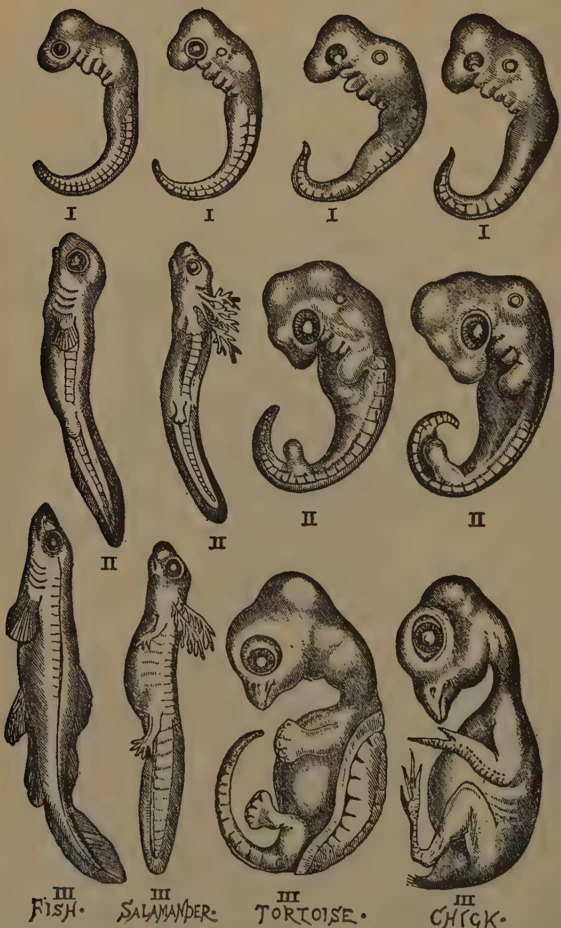


FIG. 96.—A series of embryos at three comparable and progressive stages of development (marked I, II, III), representing each of the classes of vertebrated animals. (*After Häckel.*)


I
I
I
I
II
II
II
II
III
HOG.
III
CALF.
III
RABBIT.
III
MAN.

surface to outgrow and surround the inner concave surface, the fusion or concrescence of many of the folds, the growth of groups of cells at certain points to form organs and so bring about the final evolution of the fœtus.

The external morphological development and the resemblances it embraces can be more quickly understood by an examination of the accompanying illustrations taken from Romanes than from a lengthy description.

Internal development progresses simultaneously with external development. Perhaps so much of this has been left to the imagination of the reader that it may be well to consider certain features more particularly. Let us begin by remarking that it progresses simply or complexly according to the future simplicity or complexity of the species to which the embryo belongs. Let it also be understood that in spite of complexity it progresses rapidly, and that the complexity incidental to the phylogenetic position of the animal whose embryo is examined is not the result of the consecutive formation of the internal organs, but of their simultaneous formation.

Therefore, in animals of complicated structure many different things are going on at the same time that must be separately and individually described. Again, as the embryo of a vertebrate is at no stage of its embryonal development self-supporting, all of the developmental processes look toward future needs, making no provision for immediate needs, which are provided for by the yolk or derived through the placenta (oxygen, nutriment, etc.) from the parent.

Thus, in phylogenetic development, it has been shown that the first need of the organism is food, and the first specializations have to do with the vegetative functions, so that the vegetative organs are the first to evolve, the first cell differentiation being the separation of the outer cells into protective coverings and the inner cells into nutrition providers. Following this means

must be provided for transporting the nutriment so that it may easily reach the cells not contiguous to the source of supply. The last system to appear is the correlating and coordinating central nervous system.

In the ontogenetic development of the higher animals the conditions are different, for the nourishment of the embryonal tissues is provided for by the egg yolk or by the placenta, so that the digestive organs need not be early perfected. The size of the embryo and the arrange-

FIG. 97.—The metamorphosis of the frog. The numbers indicate the sequence. (*Galloway after Brehm.*)

ment of its parts are also such that the circulatory organs need not be active before a considerable general complexity of structure is attained. There is, however, among vertebrates a general dominance of the nervous system, so that instead of the organic systems developing one after the other, as in phylogenetic progress, ontogenetic development is so modified that the dominant system first makes its appearance, and in vertebrate embryos the central nervous system which takes precedence of all others in importance is one of the first to appear.

However, though the importance and hence the order of development is changed, the general plan of development for each organ or system of organs is quite comparable to that seen in phylogenesis.

"When one traces the course of development of any vertebrate, he finds, speaking in general terms, that those fundamental characteristics more or less common to all vertebrates first appear, being followed by secondary characteristics distinguishing one class from another." In vertebrate embryos, however, before the development reaches a certain point, distinct resemblances to invertebrate forms are met, and the younger the embryo is, the more it has in common with embryos in general, until at the very beginning we come to the single germinal cell which is the starting point of every embryo. These facts have found expression in the statement that "*the ontogeny recapitulates the phylogeny.*" This as a theory is certainly justified; as a fact it must be further explained. Von Baer, in 1828, gave us the following generalizations:

1. That which is common to a large group of animals develops in the embryo earlier than that which is special.
2. From the most generalized stage, structures less generalized are developed, and so on until the most special appears.
3. The embryo of a given animal form, instead of passing through the other given forms, separates itself from them more and more.
4. Therefore, the embryo of the higher forms is never like a lower form, but only like its embryo.

These principles have since been much insisted upon, especially by Haeckel, who termed the law of recapitulation the " Biogenetic law."

The emphasis laid upon this "law" by many writers has, however, given rise to some mistakes, as students are apt to think that every embryo must and does give its complete phylogeny in its ontogeny.

In explaining this misconception, Romanes says:

"Supposing the theory of evolution to be true, it must follow that in many cases it would have been more or less advantageous

to a developing type that it should have been obliged to reproduce in its individual representations all the phases of development previously undergone by its ancestry—even within the limits of the same family. We can easily understand, for example, that the waste of material required for building up the useless gills of embryonic salamanders is a waste which, sooner or later, is likely to be done away with; so that the fact of its occurring at all is in itself enough to show that the changes from aquatic to terrestrial habits on the part of this species must have been one of comparatively recent occurrence. Now, in as far as it is detrimental to a developing type that it should pass through any particular ancestral phases of development, we may be sure that natural selection—or whatever other adjustive causes we may suppose to have been at work in the adaptation of organisms to their surroundings—will constantly seek to get rid of this necessity, with the result, when successful, of dropping out the detrimental phases. Thus the foreshortening of developmental history which takes place in the individual lifetime may be expected often to take place, not only in the way of condensation, but also in the way of excision. Many pages of ancestral history may be recapitulated in the paragraphs of embryonic development, while others may not be so much as mentioned. And that this is the true explanation of what embryologists term the 'direct' development—or of a more or less sudden leap from one phase to another, without any appearance of intermediate phases—is proved by the fact that in some cases both direct and indirect development occur within the same group of organisms, some genera or families having dropped out the intermediate phases which other genera or families retain."

Minot says, "The embryo is not a correct or adequate record of the ancestral type,

1. Because the embryos have necessities of their own which have led to their modification in the course of evolution;
2. Because the embryos consist of undifferentiated cells;
3. Because the embryo at each stage must be regarded as the mechanical cause of the next and following stages.

However, Minot declares these to be objections to the theory rather than to the facts which he believes fully justify the interpretation that ontogeny does recapitulate the phylogeny.

Though the resemblances between embryos become more and more pronounced as we follow them back

toward the egg, there is no time when embryos belonging to widely divergent organsims are precisely alike. Every embryo, at every stage of its development, is an individual of the particular genus and species to which it belongs and has at every stage peculiarities which distinguish it from every other genus or species. It is, however, invariably true that the more closely the species are related, the greater is the resemblance of their embryos at all stages, and the more widely they are separated the further back it is necessary to go to find the phylogenetic resemblances.

If we examine the developing mammalian embryo for phylogenetic resemblances, they are easily found. Every embryo begins by segmentation resulting in some kind of a morula; the morula always passes into some kind of a blastula stage, and the blastula always undergoes some kind of gastrulation. The beginning embryo is always elongate and slender. The gut is always formed by concrescence of the folded entoderm and inclosed by concrescence of the externally folded ectoderm. The vertebrate embryo diverges from all others by the preponderating importance of its nervous system and eyes, provision for which is made very early, at which time all vertebrate embryos look much alike. All of the vertebrate embryos have long tails (see the Romanes diagrams). The ventral surface becomes closed by the concrescence of buds that form the face and neck and the thoracic and abdominal walls. The branchial region of all vertebrate embryos show slits or folds where the gills of the fishes and batrachians are formed, though the mammalian embryos do not have real gill clefts at this time. In all cases the limbs first appear as buds that grow into shapeless excrescences, which subsequently elongate, differentiate, and become perfected, it being impossible to tell the final character of these members for some time after they have first appeared.

The tail persists for a surprisingly long time in the

human embryo (twenty-five days) and gives it a striking resemblance to the embryos of lower animals.

The heart makes its appearance as a simple straight tube similar to that of the invertebrates, becomes separated into an anterior ventricle and posterior auricle like that of the fishes. Later it consists of a curved organ with two incompletely separated auricles and one ventricle, not unlike that of the bactrachians. Much

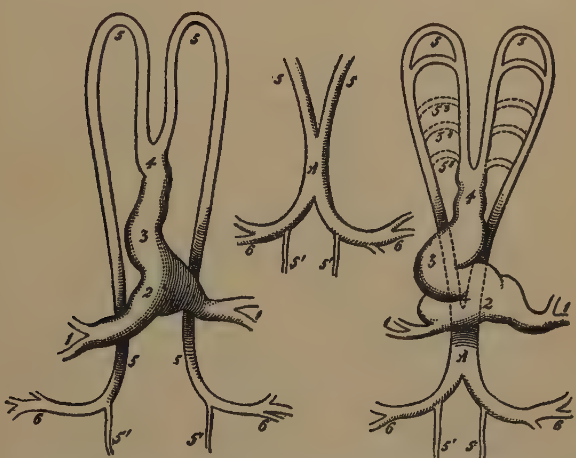


Fig. 98.—Diagrams illustrating arrangement of primitive heart and aortic arches in the human embryo. By comparing these with the diagrams showing the increasing complexity of the heart in phylogenetic development (Chapter VII) it will be seen that in the development of the human heart the autogeny repeats the phylogeny. (*Modified from Allen Thomson.*)

later it differentiates into the four-chambered viscus of the higher vertebrates.

Not only does the development of the heart thus conform to its phylogeny, but the development of the whole circulatory system coincides as well. The heart and great vessels first appear, the small vessels and capillaries later. Further, the arrangement of the arteries at first conforms with fair accuracy to that

seen in fish, then to that in the batrachians, then to that of mammals as can at once be seen by comparing the figures showing the embryology of the human heart and vessels with those of the different phylogenetic groups.

It has been shown that the first separation of the egg into two blastomeres is accompanied by a fair uniformity in the developmental power of each, so that if separated at that time, two embryos of small size may develop. Accidental separation of the primary blastomeres seems at times to occur among the highest animals, and it is probably in this manner that *homologous twins* arise. Such twins are always of the same sex; resemble each other so closely that throughout life they are frequently mistaken one for the other; possess the same general tendencies of mind and body; are predisposed to the same diseases; attain to about the same general intellectual development, and not infrequently die within a short time of each other, sometimes from the same cause. Galton's studies of homologous twins, in his book upon "The Human Faculty," are most interesting as showing how completely the homologous twins are identified.

As such twin embryos are, during their embryonal development, in close proximity to one another, there seems to be an occasional tendency for the growing cells of one embryo to become confused with those of its neighbor, with interesting resulting malformations. Thus, one-half may grow rapidly, outstrip and include the other, whose growth is consequently disturbed and inhibited, so that one fœtus with normal external configuration, but with internal confusion explainable on no other hypothesis, may arise.

Or the fœti may be equal or nearly equal in size, but blended or connected throughout, or at the cephalic, thoracic, or pelvic portions, sometimes face to face, sometimes side to side, sometimes back to back. The relative position of the conjoined parts is usually normal

—*i.e.*, the cephalic and caudal ends of the embryos correspond. Sometimes, however, they rotate until the cephalic ends are opposed and the caudal ends conjoined, or the caudal ends opposed and the cephalic ends conjoined.

In rare cases the relation of one embryonal axis to the other is lost and the attachment of one embryo to the other without correspondence of the parts.

The attachment of one individual to the other may embrace the fundamental and vital organs—heart, brain, spinal cord, etc.; or may be through comparatively unimportant structures, the twins being conjoined by a kind of slender pedicle, as in the Siamese twins.

Some knowledge of embryology likewise enables one to understand certain monstrous formations arising in single individuals. Thus the bridging of the neural canal to form the spinal canal in which the future spinal cord is to lie, is one of the first features of mammalian development. If this process fail anteriorly, the imperfect covering permits morbid changes, known as craniorrachischisis, with meningocele or encephalomeningocele, and terminating in anencephaly; when occurring posteriorly, in myelomeningocele and *spina bifida*.

Partial failure of the anterior concrescenses by which the face is formed explains the occurrence of hare-lip and cleft palate and similar incomplete fusion of the splanchnopleures and of the folds which form the genitalia, the occurrence of extrophy of the bladder, epispadias and hypospadia.

The rare cases of reversed viscera, in which the heart is in the right side, the liver in the left, and the spleen in the right—*situs inversus viscerum*—are so perfect in detail of structure, apart from the reversed condition, that they cannot be enumerated among the monstrosities, but must be looked upon as referable to occasional differences in the right or left impulse of growth in the respective eggs. This coincides with Conklin's observations upon snails' eggs.

References.

O. Hertwig: "Text-book of the Embryology of Man and Mammals." Translated by E. L. Mark, N. Y.
John C. Heisler: "A Text-book of Embryology," Phila.
L. P. McMurrich: "The Development of the Human Body," Philadelphia, 1904.
C. S. Minot: "A Laboratory Text-book of Embryology," Phila., 1903.
A. M. Marshall: "The Frog," etc., N. Y., 1906.

CHAPTER X.

CONFORMITY TO TYPE.

There are few facts better recognized, yet less understood, than that the offspring resembles its parents. Such resemblance is said to be inherited, and the qualities by which it is brought about, hereditary. The faithful transmission of these qualities not only causes each individual to resemble its parents, but also to *conform to the type* of its species. Failure in their transmission may lead to a divergence from the type and may result in the development of new species. Heredity, therefore, is of far-reaching importance, for it not only determines ontogeny, but also phylogeny.

To those who have become reasonably familiar with the reproductive processes it may not be surprising that the unicellular organisms conform to their specific types, seeing that each is but a portion of a preexisting organism whose entire reproductive energy at the time of multiplication has been directed toward securing for each resulting half an exactly equal quantity of parental substance. Nor is it surprising that a bud from a hydra should eventually come to resemble the hydra, seeing that any considerable part cut off from the hydra eventually regenerates so as to return to parental resemblance. But no amount of familiarity with the phenomena can make the thoughtful mind cease to wonder when he sees a tiny undifferentiated spore grow into a beautiful fern by which myriads of new spores will be produced, a very simple seed grow into a great tree covered with leaves and flowers, or an egg transformed without external assistance into a living, active bird covered with feathers. That so much should be potentially enclosed in a single cell, seems impossible!

What is in the egg? What is the nature of these maternal and paternal influences? How can they determine phylogeny and ontogeny? How can they determine every detail of the new being from its general configuration to the finest details of internal structure; from the color patterns upon its smallest feathers to the choice of its food, the quality of its voice, or its future habits of roosting in trees or building its nest on the ground?

Yet all this and more is accomplished without any outside influence except the degree of warmth required for the incubation. All of the forces that effect these results are intrinsic in the egg, yet without any visible explanation. Indeed some of the influences resident in eggs do not appear to become active for years after the adult individual has formed. Thus among human beings we find it to be predetermined in the egg that one shall lose his hair early or late, have his hair whiten early or late, tend to corpulence at a certain age, and even tend to die of apoplexy when a certain age is reached. It seems, therefore, as though eggs are charged with impulses so numerous, so diversified, and so persistent as to determine the entire future of the individual and leave nothing to chance or to circumstance.

It is small wonder that matters of such surpassing interest should have proved a fascinating study to thinking men in all departments of learning and that many theories should have been devised for their explanation.

Herbert Spencer[1] conceived that the form of each living creature was determined by a "peculiarity in the constitution of its physiological units, that these have a special structure in which they tend to arrange themselves, just as have the simpler units of inorganic matter." . . .

"We must conclude that the likeness of any organism to either parent is conveyed by the special tendencies of its physiological

[1] "Principles of Biology," I, p. 254, 1866.

units derived from that parent. In the fertilized germ we have two groups of physiological units, slightly different in their structures. These slightly different units severally multiply at the expense of the nutriment supplied to the unfolding germ, each kind moulding this nutriment into units of its own type. Throughout the process of evolution, the two kinds of units, mainly agreeing in their polarities and the form which they tend to build themselves into, but having minor differences, work in unison to produce an organism of the species from which they were derived, but work in antagonism to produce copies of their respective parent organisms. And hence ultimately results an organism in which the traits of the one are mixed with traits of the other."

"Quite in harmony with this conclusion are certain implications . . . noticed respecting the characters of sperm cells and germ cells. We saw sundry reasons for rejecting the supposition that they are highly specialized cells and for accepting the opposite supposition that they are cells differing from the others rather in being unspecialized. And here the assumption to which we seem driven by the *ensemble* of the evidence is, that the sperm cells and germ cells are essentially nothing more than the vehicles, in which are contained small groups of physiological units in a fit state for obeying their proclivity toward the structural arrangement of the species they belong to."

These "units" of which Spencer speaks are regarded as intermediate between the chemical units or molecules and the morphological units or cells. They must be immensely more complicated than the chemical units, and must, therefore, correspond to groups of molecules. The whole organism is supposed to be composed of them, all alike in kind, the germ cells contain small groups of them. "The former supposition makes regeneration possible to each sufficiently large portion of the body, while the latter gives the germ cell the power of reproducing the whole; inasmuch as the 'polarity' of the 'units' leads to their arrangement in such a way that the whole 'crystal,' the organism, is restored or even formed anew. The mere *difference in the arrangement* of the units alike in kind determines the diversity of the *parts of the body*, while the distinction between different species and that between different *individuals* is due to a diversity in the constitution of the units."

Weismann, in considering Spencer's theory, says that "the assumption of these 'physiological units' does not suffice as an interpretation of heredity; it proves insufficient even in interpreting the differentiation of organs in simple autogeny, quite apart from the question of amphigonic heredity. But it has the merit of having utilized the smallest vital particles as constituent elements of the organism and of having made them the basis of a theory of heredity."

Darwin[1] formulated a theory of inheritance which he at first imagined to correspond fairly well with Spencer's, though important differences were subsequently pointed out. This theory he calls *pangenesis* and explains as follows:

"It is universally admitted that the cells or units of the body increase by self-division or proliferation, retaining the same nature, and that they ultimately become converted into various tissues and substances of the body. But besides this means of increase I assume that the units throw off minute granules which are dispersed throughout the whole system; that these, when supplied with proper nutriment, multiply by self-division, and are ultimately developed into units like those from which they were originally derived. These granules may be called *gemmules*. They are collected from all parts of the system to constitute the sexual elements, and their development in the next generation forms a new being; but they are likewise capable of transmission in a dormant state to future generations and may then be developed. Their development depends upon their union with other partially developed or nascent cells which precede them in the regular course of growth. . . . Gemmules are supposed to be thrown off by every unit, not only during the adult state, but during each stage of development of every organism, but not necessarily during the continued existence of the same unit. Lastly, I assume that the gemmules in their dormant state have a mutual affinity for one another, leading to their aggregation into buds or into the sexual elements. Hence it is not the reproductive organs or buds which generate into new organisms, but the units of which each individual is composed. These assumptions constitute the provisional hypothesis which I have called pangenesis."

After a lengthy application of the theory to the facts to be explained, he concludes as follows:

"The hypothesis of pangenesis, as applied to the several great classes of facts just discussed, no doubt is extremely complex, but so are the facts. The chief assumption is that all the units of the body, besides having the universally admitted power of growing by self-division, throw off minute gemmules which are dispersed throughout the system. Nor can this assumption be considered too bold, for we know from the cases of graft-hybridization that formative matter of some kind is present in the tissues of plants, which is capable of combining with that included in another individual, and of producing every unit of the whole organism. But we have further to assume that the gemmules grow, multiply, and aggregate themselves into buds and the sexual elements;

[1] "The Variation of Animals and Plants under Domestication," 1868, II, Chapter XXVII, p. 349.

their development depending on their union with other nascent cells or units. They are also believed to be capable of transmission in a dormant state, like seeds in the ground, to successive generations."

"In a highly organized animal, the gemmules thrown off from each different unit throughout the body must be inconceivably numerous and minute. Each unit of each part, as it changes during development, and we know that some insects undergo at least twenty metamorphoses, must throw off its gemmules. But the same cells may long continue to increase by self-division, and even become modified by absorbing peculiar nutriment, without necessarily throwing off modified gemmules."

"All organic beings, moreover, include many dormant gemmules derived from their grandparents and more remote progenitors, but not from all their progenitors. These almost infinitely numerous and minute gemmules are contained within each bud, ovule, spermatozoon, and pollen grain. Such an admission will be declared impossible; but number and size are only relative difficulties. Independent organisms exist which are barely visible under the highest powers of the microscope, and their germs must be exceedingly minute. Particles of infectious matter, so small as to be wafted by the wind or to adhere to smooth paper, will multiply so rapidly as to infect within a short time the whole body of a large animal. We should also reflect on the admitted number and minuteness of the molecules composing a particle of ordinary matter. The difficulty, therefore, which at first appears insurmountable, of believing in the existence of gemmules so numerous and so small as they must be according to our hypothesis has no great weight. The units of the body are generally admitted by physiologists to be autonomous.

"I go one step further and assume that they throw off reproductive gemmules.

"Thus an organism does not generate its kind as a whole, but each separate unit generates its kind. It has often been said by naturalists that each cell of a plant has the potential capacity of reproducing the whole plant; but it has this power only in virtue of containing gemmules derived from every part. When a cell or unit is from some cause modified, the gemmules derived from it will be in like manner modified.

"If our hypothesis be provisionally accepted, we must look at all the forms of asexual reproduction, whether occurring at maturity or during youth, as fundamentally the same and dependent on the mutual aggregation and multiplication of the gemmules. The regrowth of an amputated limb and the healing of a wound is the same process partially carried out. Buds apparently include nascent cells, belonging to that stage of development at which the budding occurs, and the cells are ready to unite with the gemmules derived from the next succeeding cells.

"The sexual elements, on the other hand, do not include such nascent cells; and the male and female elements taken separately do not contain a sufficient number of gemmules for independent development, except in the cases of parthenogenesis.

"The development of each being, including all the forms of metamorphosis and metagenesis, depends on the presence of gemmules thrown off at each period of life and on their development, at a corresponding period, in union with preceding cells. Such cells may be said to be fertilized by the gemmules which come next in due order of development. Thus the act of ordinary impregnation and the development of each part in each being are closely analogous processes. The child, strictly speaking, does not grow into the man, but includes germs which slowly and successively become developed and form the man.

"In the child, as well as in the adult, each part generates the same part. Inheritance must be looked at as merely a form of growth, like the self-division of a lowly organized unicellular organism. Reversion depends on the transmission from the forefather to his descendants of dormant gemmules, which occasionally become developed under certain known or unknown conditions. Each animal and plant may be compared with a soil full of seeds, some of which soon germinate, some lie dormant for a period, whilst others perish. When we hear it said that a man carries in his constitution the seeds of an inherited disease, there is much truth in the expression. No other attempt, as far as I am aware, has been made, imperfect as this confessedly is, to connect under one point of view these several grand classes of facts. An organic being is a microcosm—a little universe, formed of a host of self-propagating organisms, inconceivably minute and numerous as the stars in heaven."

In criticising this theory of pangenesis, Galton[1] points out that though it is quite in accord with Darwin's theories and fully accounts for such features as are embraced in the hereditary transmission of those characters upon which species are supposed to separate, there are certain difficulties, both theoretical and practical, in the way of its acceptance. Thus, the gemmules given off by the cells must be looked upon as of colloidal nature and therefore cannot be supposed easily to transfuse through membranes as their free circulation in the body would necessitate. Being in large numbers in the maternal circulation, they must easily find their way into the fœtal circulation, unduly impressing the offspring with maternal material. For this reason, the offspring should much more closely resemble the maternal grandmother than any other progenitor, which is certainly not the case. If present in the circu-

[1] "A Theory of Heredity," Jour. of the Anthropological Institute, V, London, 1876, p. 329.

lation, they should pass from one animal into another if transfusion of blood were practised and then should influence the germinal cells of the animal into which they were introduced. To determine this point, Galton "largely transfused the blood of an alien species of rabbit into the blood vessels of male and female silver-gray rabbits, from which he afterwards bred." "He repeated this process for three generations and found not the slightest sign of any deterioration in the silver-gray breed." Having been criticised by Darwin for the manner in which the experiments were performed, he subsequently repeated them with improved apparatus and on an equally large scale for two more generations, but without differing results.

Galton therefore devised a new theory of heredity—the theory of the *stirp*—based upon the theory of pangenesis, but differing from it in certain essentials.

The term "stirp," from the Latin *stirpes*, a root, "is used to express the sum total of the germs, gemmules, or whatever they may be called, which are to be found, according to every theory of organic units, in the newly fertilized ovum."

The theory is postulated in four parts, thus: "1. Each of the enormous number of quasi-independent units of which the body consists has a separate origin or germ. 2. The stirp contains a host of germs, much greater in number and variety than the organic units of the bodily structure that is about to be derived from them, so that comparatively few individuals out of the host of germs achieve development. 3. The undeveloped germs retain their vitality that they may propagate themselves while still in the latent state and contribute to form the stirps of the offspring. 4. Organization wholly depends upon the mutual affinities and repulsions of the separate germs: first in their earliest stirpal stage and subsequently during all the processes of development."

"It is thus seen that the stirp itself contains all of the essential units, to which few are added—that some must

circulate and be added to those in the stirp is granted, and they explain the rare cases in which zebra marks occur on the foal of a thoroughbred mare by a thoroughbred horse, owing to the fact that the mare had previously born a mule to a zebra; but to have them circulate in such numbers and so constantly as the doctrine of pangenesis implies would over-explain such cases."

"Of the two groups of germs, the one consisting of those that succeed in becoming developed and in forming the bodily structure, and the other consisting of those that remain continually latent, the latter vastly preponderates in number." "We should expect the latent germs to exercise a corresponding predominance in matters of heredity, unless it can be shown that, on the whole, the germ that is developed into a cell becomes thereby more fertile than if it had remained latent."

The theory of the stirp transfers the hereditary material from the somatic to the germinal cells. Contrasting his views with those of Darwin, the following language is used by Galton:

1. "There are cells and there are a great number of gemmules.

2. "The cells multiply by self-division, and during this process they throw off gemmules. (I look upon this process of throwing off the gemmules to be of such minor importance as to have no effect whatever upon the cases we have thus far considered. Its existence is granted, but only as a subordinate process, to account for the exceptional cases to be hereafter considered and not as the primary process in heredity.)

3. "The gemmules multiply by self-division, and any gemmule admits under favorable circumstances of being developed into a cell. (I look upon this as the primary process in heredity.)

4. "The personal structure is formed by a process analogous to the fertilization of each gemmule that becomes developed into a cell by means of the partially developed cell that has preceded it in the regular order of growth. (I look on it as due, first, to the successive segmentations of the host of gemmules that are contained in the newly fertilized ovum, owing to their mutual affinities and repulsions; and, secondly, to the development of the dominant or representative gemmules in each segmentation, the others remaining dormant, and are called, for convenience, in the next paragraph, the residue.)

5. "The sexual elements are formed by aggregation out of the gemmules, all of which are supposed to travel freely throughout the body. (I look on the sexual elements as directly descended

become pervaded by it as a connected network. Protoplasm, including both trophoplasm and idioplasm, he considered to be compounded of exceedingly minute units no larger than a molecule of albumen, to which he gave the name *micellæ.* These were capable of multiplication, not by division, but through the formation of new ones between those already existing. The germinal cells contain both trophoplasm and idioplasm, the latter governing the growth of the former as it increases itself. In this theory the thought of the continuity of the germinal substance is foreshadowed. Charles Sedgwick Minot suggested that Nageli's "idioplasm" might be identified with the nuclear chromatin.

Gustav Jäger in 1878 seems to have been the first to express the idea that in the higher organisms the body consists of two kinds of cells which he called the "autogenetic" and "phylogenetic," respectively, and that the latter or reproductive cells are not the product of the former, or body cells, but are derived directly from the germ cell of the parent.

Rauber in 1880 conceived that the effect of fertilization was to convert a portion of the egg, namely, the personal part, into the form of a person; the other portion does not experience this effect, for it has stronger powers of persistence.

Nussbaum in 1880 also foreshadowed the idea of the continuity of the germ cells, and supposed that the segmented ovum divides into the cell material of the individual and the cells for the preservation of the species. These ideas remained unnoticed until Weismann's theory was evolved in 1892.

The theory of the "*germ plasm*" was the work of Weismann and, though it may be subject to valid objections, contains so large a proportion of truth that it has taken a strong hold upon the thought of the day and forms the basis of a large part of biological speculation. It is essentially a cytological theory, and though it follows the thought expressed in the theories preceding

by multiplication during the preparation of succeeding generations.

The doctrine of gemmules formed the foundation of another theory of inheritance suggested by Brooks. Upon superficial examination the theory closely resembles the theory of Darwin, but differs from it in certain important points. Thus, though Brooks agrees with Darwin that gemmules are given off by all the cells of the body and that they circulate in the blood from which they centre in the germ cells, he differs in ascribing to the male germ cell a strong affinity or attracting power over the gemmules so that it collects a special mass of them and stores them up. The egg cell is the conservative principle which controls the transmission of the purely racial or specific characters, whereas the sperm cell is the progressive element which causes variation. The two kinds of germ cells are charged with gemmules in different degrees. The theory is chiefly aimed at the explanation of variation which is supposed to be caused by every gemmule of the spermatozoon uniting with that particular gemmule of the ovum that is destined to give rise, in the offspring, to the cell which corresponds to the one which produced the germ or gemmule. When this cell becomes developed in the body of the offspring it will be a hybrid and will therefore tend to vary.

It will be observed by the thoughtful reader that with the progress of knowledge more attention was being devoted to the germ cells and less to the somatic cells. This will be made more clear by the thoughts expressed in the ensuing theories.

Nageli conceived that the body was made up of two different materials, the *trophoplasm* or nutrient plasm, and *idioplasm* or germ plasm. The latter, though present in small quantity, determines the detailed construction of the former. He conceived the idioplasm to form a very fine network of fine fibers which traverse the cells, continuing from cell to cell so that all parts of the body

become pervaded by it as a connected network. Protoplasm, including both trophoplasm and idioplasm, he considered to be compounded of exceedingly minute units no larger than a molecule of albumen, to which he gave the name *micellæ.* These were capable of multiplication, not by division, but through the formation of new ones between those already existing. The germinal cells contain both trophoplasm and idioplasm, the latter governing the growth of the former as it increases itself. In this theory the thought of the continuity of the germinal substance is foreshadowed. Charles Sedgwick Minot suggested that Nageli's "idioplasm" might be identified with the nuclear chromatin.

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it, that some kind of physiological units are engaged in the phenomena of heredity and centres them in the germ plasm which is believed to be continuous from generation to generation, it progresses much further and proposes to show the source of the germ plasm and the exact location, distribution, and treatment of the units.

As Weismann's theory is of such importance, it will be dwelt upon at some length and as nearly as possible be given in the author's own language.

"All the phenomena of heredity depend upon minute vital units which we have called *biophors* and of which living matter is composed: these are capable of assimilation, growth, and multiplication by division. We are unacquainted with the lowest conceivable organisms, and do not even know if they still exist. But they must at any rate have done so at some time or other, in the form of single biophors, in which multiplication and transmission occurred together, no special mechanism for the purpose of heredity being present. When the body became constructed in a more or less complex manner, of various kinds of biophors arranged in a definite manner, simple binary fission no longer sufficed for the transmission of the characters of the parent to the offspring. If the parts situated in the anterior, posterior, right, left, dorsal, and ventral regions differed from one another, all the elements—*i.e.*, all the kinds and groups of biophors—could not by any method of halving, be transmitted to both the offspring resembling the parent. Special means must then have been adopted to render such a completion and consequent perfect transmission possible; *and this was attained by the formation of a nucleus.* We may regard the nucleus as having originally served merely for the storage of reserve biophors. Subsequently—that is, in multicellular organs possessing highly differentiated cells—the nucleus took on other functions, which regulated the specific activity of the cell, though it still retained biophors capable of supplying the characters of the cells which were still wanting and therefore still better served as the bearer of the biophors controlling the character of the cell. If, therefore, a special apparatus for transmission became necessary in the hetero-biophorids or unicellular organisms and appeared in the 'cell' in the form of a '*nucleus,*' it must have become still more complex on the introduction of the remarkable process of *amphimixis*, which, in its simplest and original form, consists in the complete fusion of two organisms in such manner that nucleus unites with nucleus and cell body with cell body (conjugation). In the higher unicellular organisms this process is, in most cases, restricted to the fusion of the nuclei half the nucleus of one animal uniting with half that of another. The process of division shows that the nucleus has a structure precisely analogous to that of the nucleus in multicellular organisms; we may, therefore, assume that the hereditary sub-

stance here likewise consists of several equivalent groups of biophors, constituting, 'nuclear rods' or '*idants*,' each of which contains all the kinds of biophors of the organism, though they deviate slightly from one another in their composition as they correspond to individual variations. Half the idants of two individuals become united in the process of amphimixis and thus a fresh intermixture of individual characters results.

"The apparatus for transmission in those multicellular organisms in which the cells have undergone a division of labor is essentially similar to that seen in unicellular beings; although in correspondence with the greater complexity of their structure it is more complicated.

"As the process of amphimixis occurs in them also, and the fission of the highly differentiated multicellular individuals seems to be only possible by a temporary return to the unicellular condition, we find that the so-called 'sexual reproduction,' which is of general occurrence among them, consists in all the primary constituents (Anlagen) of the entire organism being collected together in the nucleus matter of a single reproductive cell.

"Two kinds of such cells, which are differently equipped and mutually attract one another, then unite in the process of amphimixis and constitute what we are accustomed to call the 'fertilized egg cell,' which contains the combined hereditary substance of two individuals. According to our view, this hereditary substance of the multicellular organisms consists of three orders of vital units, the lowest of which is constituted by the *biophors*. In the unicellular forms a more or less polymorphic mass of biophors having a definite arrangement, constitutes the individual nuclear rods or *idants* (chromosomes), several of these making up the hereditary substance of the nucleus which controls the cells; and similarly in these higher forms, groups of biophors, arranged in a certain order, constituting the primary constituents of the individual cells of the body, and together form the second order of vital units—the *determinants*. The histological character of every cell in a multicellular organism, including its rate and mode of division, is controlled by such a determinant. The germ cell, however, does not contain a special determinant for every cell unless it is to remain independently variable. *The germ cell of a species must contain as many determinants as the organism has cells or groups of cells which are independently variable from the germ onwards,* and these determinants must have a definite mutual arrangement in the germ plasm, and must therefore constitute a definitely limited aggregate, or higher vital unit, the '*id*.' From the facts of sexual reproduction and heredity we must conclude that the germ plasm contains many ids, and not a single one only. The formation of hybrids proves that the two parents together transmit all their specific characters, so that in the process of fertilization each contributes a hereditary substance which contains the primary constituents of all parts of the organism—that is, all the determinants required for building up the new individual. The hereditary substance becomes halved at the final stage of development of the germ cells, and consequently all the deter-

minants must previously have been grouped into at least two ids. But it is very probable that many more ids are usually present and that in many cases their number far exceeds a hundred. It cannot be stated with certainty which portions of the elements of the germ plasm observable in the nucleus of the ovum correspond to the ids, though it is probable that only parts of and not the entire 'chromosomes' are to be regarded as such. Until this point can be definitely decided, our further detailed deductions will be based on the view that the nuclear rods (chromosomes) are aggregates of ids, which we speak of as '*idants*.' In a certain sense these are also vital units for they grow and multiply by division; and the combination of ids contained in them, although not a permanent one, persists for some time.

"The 'germ plasm,' or hereditary substance of the metazoa and metaphyta, therefore, consists of a larger or smaller number of idants, which in turn are composed of ids; each id has a definite and special architecture, as it is composed of determinants, each of which plays a perfectly definite part in development.

"The development of the primary constituents in the germ plasm of the reproductive cell takes place in the course of the cell divisions to which the autogeny of a multicellular organism is due, in which process all the ids behave in exactly similar manner. In the first cell-division every id divides into two halves, each of which contains only half the entire number of determinants; and this process of disintegration is repeated at every subsequent cell-division, so that the ids of the following autogenetic stages gradually become poorer as regards the diversity of their determinants, until they finally contain only a single kind.

"Each cell in every stage is in all cases controlled by only *one* kind of determinant, but several of the same kind may be contained in the id; and the 'control' of the cell is effected by the disintegration of the determinants into biophors which penetrate through the nuclear membrane into the cell body; and there, according to definite laws and forces of which we are ignorant, bring about the histological differentiation of the cell, by multiplying more rapidly at the expense of those biophors already forming in the cell body. Each determinant must become 'ripe,' and undergo disintegration into its biophors at a definite time or at a certain stage of autogeny. The rest of the determinants in the id of a cell, which are destined for subsequent stages, remain intact, and have therefore no effect on the control of the cell; but the mode of their arrangement in the id and the special rate of multiplication of each kind determine the nature of the next nuclear division—that is, as to which determinants are to be distributed to one daughter cell and which to the other. The histological nature of these two cells, as well as the control of their successors, is determined by this division; and thus the distribution of the primary constituents contained in the germ plasm is effected by the architecture of the id, which is at first a definite kind, but afterward undergoes continual and systematic changes in consequence of the uneven rate of multiplication and gradual disintegration of the ids.

"The apparatus for cell-division is only of secondary importance in the process; its chief part, the centrosome, like the hereditary substance, is derived from the parental germ cell or cells, but only constitutes the mechanism for the division of the nucleus and cell and contains no 'primary constituents.' The rate of cell-divisions cannot, moreover, be determined by the centrosome, although it produces the primary stimulus; the apparatus for division is set in motion by the cell, which is controlled by the idioplasm. Were this not the case, the nuclear matter could not be the hereditary substance, for most of the hereditary characters of a species are due in a less degree to the differentiation of individual cells than to the number and grouping of the cells of which a certain organ or entire part of the body consists; these, however, again depend on the mode and rate of cell-division.

"The processes occurring in the idioplasm which direct the development of the organism from the ovum—or, to speak in more general terms, from one cell, the germ cell—do not in themselves furnish an explanation of a series of phenomena which are in part directly connected with the autogeny, or else result from it sooner or later; the phenomena of *regeneration*, *gemmation*, and *fission*, and the *formation of new germ cells*, all require special supplementary hypotheses.

"The simplest cases of regeneration are due to the fully formed tissue, consisting of similar cells, always containing a reserve of young cells, which are capable of replacing a normal or abnormal loss. This is, however, insufficient in the more complex cases, in which entire parts of the body, such as the tail or limbs, are regenerated when they have been forcibly removed. We must here assume that the cells of the parts which are capable of regeneration contain 'supplementary determinants' in addition to those which control them, and that these are the primary constituents of the parts which are formed anew in the process of regeneration. They are supplied to certain parts of the body at an earlier autogenetic stage in the form of 'inactive accessory idioplasm,' and only become active when the opposition to growth has been removed in consequence of the loss of the part in question. The equipment of a cell of any part with supplementary determinants presupposes a greater complexity in their distribution, in correspondence with the greater complexity in structure of the part; and thus the capacity for regeneration is limited, for a part can no longer be provided with an apparatus for regeneration when its structure is too complicated. The ordinary assumption that the regenerative 'force' decreases as the complexity in structure increases is therefore to a certain extent true, but not if it implies the existence of a special force which provides for regeneration and which always diminishes in correspondence with the degree of organization.

"*Reproduction by fission* is closely connected with regeneration; it presupposes the existence of a similar apparatus in the idioplasm, which, however, has in most cases reached a higher stage of development: fission must have arisen phyletically from regeneration.

"The origin of multiplication by *gemmation* and the phenomena exhibited by this form of reproduction are different from those concerned in fission. In plants and Cœlenterates gemmation originates in one cell, which must consequently contain a combination of all the determinants of the species closely resembling that existing in the fertilized ovum. In the Polyzoa, however, this process does not originate in one cell, but in at least two, and probably more, belonging to two different layers of cells (germinal layers) of the body; and in Tunicata, again, the material for the bud is produced from all three germinal layers. The first of these forms of budding must be primarily due to the mixture of 'unalterable' germ plasm to certain series of cells in autogeny in the form of inactive '*accessory idioplasm,*' or '*blastogenic' idioplasm.* In plants this is contained in the apical cells, and in the hydroid polyps in the cells of the ectoderm. In the second group of animals mentioned, we must assume that the 'blastogenic' germ-plasm becomes disintegrated into two groups of determinants at an early autogenetic stage and that each of these is passed on in an 'unalterable' condition, through various generations of cells, until the time and place of its activity are reached. In the third group, the inactive 'blastogenic' idioplasm divides into three groups of determinants, one of which passes into the ectoderm, the second into certain cell series of the mesoderm, and the third into others in the endoderm, until they reach the part in which they have to become active.

"Gemmation must have originated phyletically by a doubling of the germ plasm taking place in the fertilized egg so that one half remained inactive and was then passed on as inactive 'blastogenic' germ plasm, or else became divided up in the course of autogeny into groups, which were passed separately to the same region, viz., that of the bud.

"We assume that *two kinds of germ plasm exist in those species in which alternation of generation occurs*, both of which are present in the egg cell as well as in the bud, though only one of them is active at a time and controls autogeny while the other remains inactive. The alternating activity of these two germ plasms causes the alternation of generations.

"The *formation of germ cells* is brought about by the occurrence of similar processes in the idioplasm to those which cause gemmation. One part of the germ-plasm contained in the fertilized egg cell remains inactive and 'unalterable'; that is, it does not immediately become disintegrated into groups, but is passed on in the form of accessory idioplasm to certain series of cells in autogeny, and thus reaches the parts in which germ cells are to be formed. Thus, the whole of the parental germ plasm, with all its determinants, forms the foundation of the germ cells which give rise to the next generation, and the extremely accurate and detailed transmission of the parental characters to the offspring is thereby rendered comprehensive.

"In multicellular plants and animals, the germ plasm becomes more complex in consequence of *sexual reproduction*, in which process the ids of two different individuals, the parents, are

accumulated in the fertilized egg cell every time amphimixis occurs. This has caused the occurrence of the 'reducing division,' which accompanies the formation of male and female germ cells, and results in the number of ids and idants being reduced to the half. As the reduction does not always occur in the same way, and the resulting halves contain different idants on different occasions, and these fall to the share of individual germ cells, it is possible for the germ cells of one individual to contain very different combinations of idants. This results in the dissimilarity between the offspring of the same parents or, to express it in more general terms, in the extreme diversity as regards the intermixture of individual differences.

"The type of the child is determined by the paternal and maternal ids contained in the corresponding germ cells meeting together in the process of fertilization, and the blending of the parental and ancestral characters is thus predetermined, and cannot become essentially modified by subsequent influences. The facts relating to identical twins and to plant hybrids prove that this is so.

"Reversion to grandparents and great-grandparents or to uncles and aunts may be accounted for by the fact that, in the first place, the idants and the ids are not formed anew in the germ plasm of the parents, but are derived from the grandparents; and, secondly, that the combination of ids contained in the individual germ cells of the parents become very diversified in consequence of the 'reducing division.'

"The number of ids of any particular ancestor which are contained in the germ plasm of a ripe germ cell depends entirely on the manner in which the reducing division occurs; and, under certain circumstances, a germ cell might presumably contain half the entire number of ids of one grandparent and none of those of the other three. The larger the number of ids derived from an ancestor, the greater is the probability that some of the characters of this ancestor will appear in the descendants; but this depends on the force of the ids of the other parent which comes into play when amphimixis takes place, and also on whether the ids derived from this ancestor are the dominant ones which determine his 'type.'

"From this theory it could be predicted that hybrid plants fertilized with their own pollen must produce very variable offspring, and that individuals of these hybrids must, moreover, revert to one or other of the ancestral species; both these statements are borne out by fact.

"The more remote the ancestors to the characters of which reversion occurs, the more rarely will it take place. Reversion to the three-toed ancestors of the horse, for instance, is of extremely rare occurrence for it is due to the retention of ancestral determinants which have certainly disappeared from all the ids in the germ plasm of most existing horses.

"The remarkable phenomenon of *dimorphism*, which has been so extensively introduced—more especially into the animal kingdom—by means of sexual reproduction must be due to the presence in the idioplasm of *double determinants* for all those cells, groups

of cells and entire organisms which are capable of taking on a male and female form. But only one half of such a double determinant remains inactive, while the other remains active. The sexual differentiation of the germ cells must thus be due to the presence of Spermatogenetic and Oogenetic double determinants; and even all the secondary sexual characters must be traced to a similar origin in the idioplasm.

"The assumption of double determinants is also able to throw some light upon certain enigmatical phenomena of heredity exhibited by human beings. It has long been known that *hemophilia* (the bleeder's disease) occurs in men only, but is transmitted by women. This disease, like a secondary sexual character, is only transmitted to the sex in which it first appeared, *for this half of the double determinants of the 'mesoblast germ' has alone been modified by the disease.*

"It is self-evident from the theory of heredity here propounded that only those characters are transmissible which have been controlled—*i.e.*, produced—by determinants of the germ, and that consequently only those variations are hereditary which result from the modification of several or many determinants in the germ plasm, and not those which have arisen subsequently in consequence of some influence exerted upon the cells of the body. In other words, it follows from this theory that *somatogenic or acquired characters cannot be transmitted.*

"This, however, does not imply that external influences are incapable of producing hereditary variations; on the contrary, they always give rise to such variations when they are capable of modifying the determinants of the germ plasm. Climatic influences, for example, may well produce permanent variations by slowly causing gradually increasing alterations to occur in the determinants in the course of generations. The primary cause of variation is always the effect of external influences. When deviations only affect the soma, they give rise to temporary, non-hereditary variations; but when they occur in the germ plasm, they are transmitted to the next generation and cause corresponding *hereditary variations in the body.*"

The chief feature of Weismann's theory is thus expressed by Wilson: "It is a reversal of the true point of view to regard inheritance as taking place from the body of the parent to that of the child. The child inherits from the parent *germ cell,* not from the parent body, and the germ cell owes its characteristics not to the body which bears it, but to its descent from a pre-existing germ cell of the same kind. Thus the body is, as it were, an offshoot from the germ cell. As far as inheritance is concerned, the body is merely the carrier of the germ cells which are held in trust for coming generations."

It goes without saying that so suggestive and complete a theory as that of Weismann must take a strong hold and leave a deep impression upon the thoughtful mind. Whatever may be thought of the biophors, determinants, ids, and idants—and some, like Adami, believe that they have demolished this elaborate succession by showing the physical impossibility of a sufficient number of them being packed away in the germ plasm—the doctrine of the continuity of the germ plasm remains unassailed and forms the foundation of much of the thought of the present day.

During these lengthy excerpts from the writings upon inheritance the reader cannot but have observed that

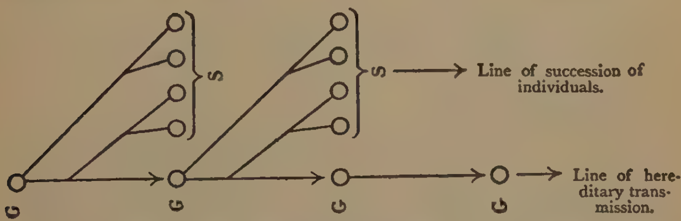


FIG. 99.—Heredity of germ cells and somatic cells. G, Germ cells; S, somatic cells. (*Lock.*)

an important difficulty to be overcome, and one upon which considerable time has been spent, is the appearance in the offspring of peculiarities not found in his parents, though present in his earlier forbears. Light upon this obscure subject is found in the thoughtful and important work of Gregor Johann Mendel, an Austrian botanist, who for a number of years studied the phenomena of hybridity among certain peas. His writings, being published in an obscure journal, were overlooked partly for that reason and partly because they appeared in 1866 when Darwin was impressing the whole world with his plausible theory of the "Origin of Species by Natural Selection" which so changed scientific thought as to make experiments upon hybridity appear futile.

The writing was discovered in 1900 by de Vries, who called attention to its great importance, excited interest in Mendel's problems, and aroused such enthusiasm among scientists generally that the paper was translated and republished with an introductory note by W. Bateson in the Journal of the Royal Horticultural Society of London, Vol. XXIV, 1901–02.

In considering Mendel's work it must not be forgotten that it is a study of *hybrid* characters and that in consequence all that was found need not apply to normal reproduction, but it must be remembered that hybrids, through the striking dissimilarities of their parents, some of which are combined in the offspring, enable us to trace given characteristics with ease because of their conspicuousness. It is the ability to recognize the Mendelian characters that has made it possible to formulate a law as to their mode of transmission.

Mendel worked with peas because the sexual organs of these flowers are enclosed by the petals in such manner that self-fertilization is inevitable. To make the hybrids, he had to cut away part of the flower, remove the unripe anthers, and at the time of the maturation of the stigma apply such pollen as was desired.

It was soon discovered that certain characters of the peas were traceable from generation to generation, appearing in recognizable form in the normal individual and in the hybrid. Such characters are, for example, color of the flower, size of the plant, quantity of sugar in the seed, and quantity of starch in the seed. These characters which appear to blend with their opposites in the hybrids of the first generation are found by an examination of the second generation to have effected a temporary combination which loosens up and begins to separate, so that with each succeeding generation a greater number of the offspring revert to the parental types until after, say, ten generations scarcely any hybrid organisms remain.

These facts were in thorough accord with well-known

facts concerning flowers. Many of our most beautiful garden flowers are hybrids, some of which were produced only after infinite pains had been taken in their cultivation. If they are fertile and "go to seed," everyone that has enjoyed a garden knows with what dismay he views the plants growing from the hybrid seeds which yield a few of the desired forms among a large number

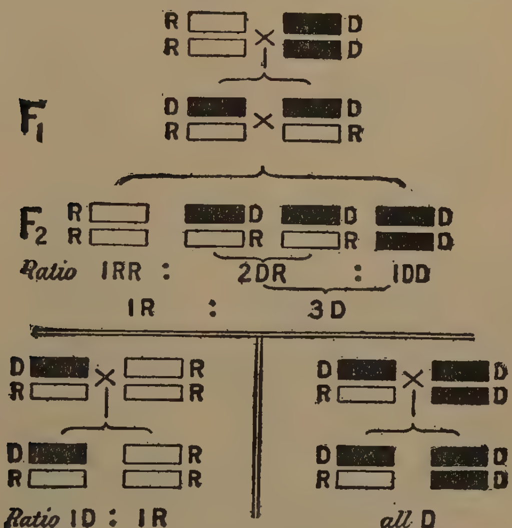


FIG. 100.—Schema of Mendel's law for a single pair of "antagonistic" properties: *A*, The results of hybridization of a pure dominant (D) with a pure recessive (R) form; *B*, the results of crossing a hybrid with a recessive form (50 per cent. of progeny pure recessive, 50 per cent. hybrid but apparently dominant); *C*, the result of crossing a hybrid with a dominant form, all apparenty dominant (but 50 per cent. pure, 50 hybrid). (*Bateson.*)

of simple and commonplace flowers. Though this fact was known in Mendel's time, and it was generally conceded that hybrids "tended to revert to the primitive types," he alone had the genius to follow the matter with scientific accuracy, to reduce the reversion to a mathematical basis, and to lay the foundation of a new

principle of much importance in studying the problems of heredity.

The disposition of these characteristics traceable from either parent into the hybrid shows that each hybrid is not, so to speak, composited of two factors, but compounded of many units, which must occur as such in the germ plasm. To such of these units as are found to undergo segregation in the germ plasm of the hybrid, and consequent separation in its offspring, Bateson has given the name *Allelomorphs.* The allelomorphic units are found to go in pairs, the individuals being separable and therefore capable of varying combinations. Germinal cells in which the allelomorphic units are of the same kind are said to be *homozygous;* those in which they are of opposed kinds, *heterozygous.*

The accompanying diagram will assist the reader in forming a concept of these allelomorphs, their occurrence in pairs, their possible separation, and their appearance in new combinations.

It is difficult to find a satisfactory concise definition of what is known as Mendel's law, seeing that he did not formulate it in words himself.

The facts upon which the law is based are displayed in the following tabulation taken from Mendel's own paper, and show that interbreeding among hybrids results in the progressive separation of the combined characters and in increasing number of reversions to the pure specific types. Before the tabulation can be understood, however, it becomes necessary to say a few words about the terms *dominant* and *recessive* as applied to the Mendelian characters. The characters, which it will be remembered go in pairs, are opposed to one another in quality and take precedence over one another in character. Thus, whiteness and blackness are opposed Mendelian characters, of which blackness takes precedence over the whiteness, and is, therefore, dominant; *i.e.*, whenever blackness is present it can be seen whether there be some whiteness in the individual or not, but

whiteness may be present and completely concealed by blackness. Mendel's tabulation of what happens when only two sets of characters are concerned is shown thus:

A. Dominant character; a, recessive character; Aa, hybrid. For brevity's sake it is assumed that each plant produces only four seeds (peas).

Generation	A	Aa	a	Ratio
				A : Aa : a
1	1	2	1	1 : 2 : 1
2	6	4	6	3 : 2 : 3
3	28	8	28	7 : 2 : 7
4	120	16	120	15 : 2 : 15
5	496	32	496	31 : 2 : 31
				2 —1 : 2^n : 2—1

In the tenth generation, therefore, $2^n - 1 = 1023$. In each 2,048 plants that arise in this generation 1,023 will show constant dominant character, 1,023 will show constant recessive character, and only two will be hybrids.

Thus, there is a spontaneous tendency to escape from hybridity, taking place under the most favorable conditions with a regularity susceptible of mathematical calculation and of formulation as a law.

Spillman expresses the Mendelian law thus: "In the second and later generations of a hybrid, every possible combination of the parent character occurs, and each combination appears in a definite portion of the individuals." With more technical diction Lock defines it thus: "The gametes of a heterozygote bear the pure parental allelomorphs completely separated from one another, and the numerical distribution of the separate allelomorphs in the gametes is such that all possible combinations of them are present in approximately equal numbers." . . . "The male and female germ cells of hybrid plants contain each of them one or the other member only of any pair of differentiating characters

exhibited by the parents, and each member of such a pair of characters is represented in an equal number of germ cells of both sexes. Separate pairs of differentiating characters (allelomorphs) conform to this law in complete independence of one another.

De Vries expresses Mendel's law in the following simple language: "The pairs of antagonistic characters in the hybrid split up in their progeny, some individuals reverting to the pure parental types, some crossing with each other anew, and so giving rise to new generations of hybrids. . . . In fertilization the characters of both parents are not uniformly mixed, but remain separated, though most intimately combined in the hybrid throughout life. They are so combined as to work together nearly always, and to have nearly equal influence on all the processes of the whole individual evolution. But when the time arrives to produce progeny, or rather to produce the sexual cells through the combination of which the offspring arises, the two parental characters leave each other and enter separately into the sexual cells. From this it may be seen that one-half of the pollen cells will have the quality of one parent and the other the quality of the other. And the same holds good for the egg cells. Obviously, the qualities lie latent in the pollen and in the egg, but ready to be evolved after fertilization has taken place."

According to Mendel's law, the unexpected appearance in the offspring of characters not found in any but remote parents may be accounted for by the presence of recessive allelomorphs which have not until the present generation been able to escape the dominance of the opposed character.

Mendel's discoveries regarding dominance are of the greatest importance to every student of the problems of heredity and are well synoptized by Castle thus:

1. "The offspring of two parents, differing in respect of one character, all resemble one parent and therefore possess the dominant character, that of the other parent being recessive or latent.

PLATE 3

Mendelian proportions in maize. Cobs born by heterozygote plants pollinated with the recessive, showing equality of smooth and wrinkled and of colored and white grains (*Lock*).

2. "In the place of simple dominance there may be manifest in the intermediate hybrid offspring an intensification of character or a condition intermediate between the two parents; or the offspring may have peculiar character of their own (heterozygotes).

3. "A segregation of the characters united in the hybrid takes place in their offspring so that a certain per cent. of these offspring possess the dominant character alone, a certain per cent. the recessive character alone, while a certain per cent. are again hybrid in nature."

When the attempt is made to follow a number of Mendelian characters at the same time, the whole matter becomes extremely complicated.

When hybrids result from combinations of totally different species they are usually infertile, have no progeny, and so die without affording an opportunity for the Mendelian law to be operative.

It is sometimes difficult to prejudge what characters may be subject to the Mendelian law. Thus whiteness and color are Mendelian characters among most plants and among the lower animals, but whiteness and blackness of the human skin are not Mendelian. On the other hand, the color of the human eyes appears to be a Mendelian character. Many spontaneously appearing pathological conditions are Mendelian, as, for example, *polydactylism* or excessive fingers and toes, *hemophilia* or bleeder's disease, etc. The frequency with which generations are skipped in the heredity of such conditions is fully explained by the laws of dominance and recession.

One of the most recent theories of heredity, meriting attention, is a chemico-physical theory which may be described as the Lateral Chain Theory of Adami.

In his "Principles of Pathology" Adami introduces and explains the theory as follows:

"We have already laid down that the primordial living matter of the cell is contained in the nucleus; it is this matter that must be carried over in the chromosomes. From this it follows that our theory must be expressed in terms of biophoric molecules, and that we have to endeavor to conceive a constitution of, and mode of introduction between these biophores from the two parental germ cells which will satisfy the various conditions. Coming now to an analysis of the different forms of inheritance, we may

make out that a particular feature showing itself in either parent may:

A. Present itself also in the offspring:

1. Dominant, wholly replacing the corresponding but divergent feature seen in the other parent.
2. Blended, this particular feature in the offspring being intermediate in character between that exhibited in the two parents.
3. In mosaic form, in certain cells the paternal, in others the maternal feature being dominant.
4. Blended and excessive, the features being more pronounced than in either parent.

B. Be unrecognizable in the offspring:

1. Recessive, and replaced by the corresponding feature derived from the other parent, but as such latent, capable of reappearing in later generations.
2. Absent, wholly wanting in subsequent generations, the absence being due either:
   a. To casting out of an inherited condition, or
   b. To the feature seen in the parent being an acquirement and not an inheritance.

"On the other hand, considering the individual, we note that as regards any particular feature or group of features there may be:

A. *Normal Inheritance.*—The offspring not being in this respect advanced beyond either parent, but at the same time not fallen behind.

B. *Progressive Inheritance.*—The offspring being advanced beyond the more advanced of the two parents and exhibiting either:

1. Excessive development of the condition or conditions already observable in one or both parents, or
2. Spontaneous variations (mutation); *i.e.*, the appearance of conditions not previously noted in either parent or either parental stock.

C. *Retrogressive* or *Reversionary Inheritance.*—The offspring reverting as regards any feature or group of features to a lower stage in the phylogeny of the species.

D. *Non-inheritance.*—Apparent or actual.

"From this analysis one thing at least is obvious, namely, that the biophores derived from either parent are liable to retain their identity for some generations. Or, to be more accurate, that qualities conveyed by the parental biophores may be retained, even if in a recessive or latent condition.

"That, indeed, is clearly proved by the Mendelian studies on hybridization: after six generations or more with self-fertilization the hybrid can give origin to plants exhibiting the pure features of either the dominant or recessive ancestor. Conjugation cannot, therefore, be of the nature of a chemical union of the biophores from the two sources with resultant formation of a new biophoric substance. On the other hand, we cannot conclude that all the separate biophores contributed by and representing each ancestor are potentially present in the fertilized ovum. This would

demand an infinite number. The existence of determinants, such as Weismann conceived, is, as we have pointed out, a physical impossibility, and this is equally so, were ten generations represented that would demand the presence in each chromosome of more than one thousand separate orders of biophores.

"Our way, then, lies between Scylla and Charybdis. Still, between those two the cautious mariner could advance his craft and, the gods helping, could achieve through the straits. And here we would urge that our conception of the constitution of the biophore affords us a proper equipment to achieve the passage. We have, it will be remembered, been led onward to regard the biophoric molecules as composed of a central body or ring of nuclei provided with side chains which are dissociated with the greatest ease. As the environment has been modified, so have the side chains undergone modification, and as these side chains become utilized in the polymerization of the biophoric matter and the formation of new biophores, so there has been a progressive increase in the complexity of the biophoric molecule.

"We have pointed out how, neglecting determinants, we must regard the biophores in the somatic cells as undergoing extensive modification when their environment has become altered, whereby they have given rise to or controlled the different orders of cells in the different tissues. As regards the germ cells, their biophores must similarly be influenced, for it is upon their modification that the whole evolution of living forms has depended. Clearly, the biophores of the human ovum are vastly more complicated than those of the amœba or, again, than those of the lowest multicellular organism of the line of man's ascent, and yet the progressive elaboration of the soma or body throughout the course of the ascent has been the outcome of the germ plasm and the biophores of the same within ovary and testis.

"There are two or three possible causes for the progressive variations of multicellular organisms: the mingling of the germ plasms in conjugation (amphimixis), the effect of environment on the respective germ plasms, and the effect of both of these combined. The first of these was strenuously upheld for long by Weismann as the controlling cause, but he was compelled to admit that the second must also be in action. In regard to this second cause, we have demonstrated that it is clearly in action in unicellular organisms that do not conjugate, as also in the somatic cells of the highest multicellular forms of life; it is illogical to deny its action upon the germ cells of the same. Not to waste time by taking part in what has been an angry discussion, we are prepared to accept the third course—to admit that both the action of external agencies and amphimixis are factors in variation, retrogressive as well as progressive.

"Granting this, and admitting that through the action of both it comes to pass that the germinal biophores in no two members of the same species are absolutely alike in constitution, what must we conceive to be their action upon each other when, through conjugation, biophores of two orders come together in the same cell, the fertilized ovum?

"The facts of inheritance and what we know regarding its histological basis entirely refute the hypothesis that the biophore molecules as a whole undergo chemical union. We may therefore conceive these, in the first place, as lying side by side in a common cytoplasm or, to be more exact, nuclear sac, in the process of assimilation attracting ions in the surrounding medium, building these up into side chains of different orders. Of these side chains some are identical—common, that is, to the molecules of both sets of biophores—some, on the other hand, of unlike constitution, so that certain side chains having corresponding position or attachments in the two sets of parental biophores are dissimilar. As demonstrated by studies upon immunity, we regard such side chains as detachable and apt to be detached, that is, to be developed in excess, and then becoming loose, passing into the surrounding cytoplasm. Again, as we have pointed out, we must regard growth and increase in the number of biophores, as brought about in the first instance by the building up of nuclei or side-chain matter, this matter attracting other matter in due order, so that gradually new rings are constituted—new biophores. If these views be correct, then, when the molecules of closely allied constitution and properties are growing side by side, what is there in this process to determine that side-chain matter which has been liberated under the influence of one set of biophores and has become detached does not become attracted to and built up into the substance of the 'growing biophores' of the other set? I cannot but hold that under these conditions—that is, conditions under which we have compound molecules of very similar structure becoming built up side by side—this must inevitably occur in a common fluid medium.

"Whenever a greater affinity exists between the components of one growing biophore and certain side-chain nuclei developed under the influence of the molecules of the other set of biophores, then these nuclei will be apt to be built into, to become an integral part of, the new biophores, to the exclusion of the corresponding nuclei—those proper to the original molecules. In short, there will be, physically speaking, a contest between the two orders of growing biophores, and, to a certain degree, a selection or rearrangement of constituent nuclei. This rearrangement in the simplest case will result in an interchange of constituent parts; in other cases may result in side-chain material derived from one parental biophore, and possessing powerful affinities to the growing biophores of both orders, becoming built up into both sets, to the exclusion of corresponding but weaker side chains (so that these become wholly cast out) and with this the properties determined by their presence disappear in the next generation. In other cases, again, we can premise an interaction between certain side-chain groups derived from the two parental biophores, the resultants of this interaction becoming built up into the growing biophores, the interaction having as a result either an exaltation or a depression of parental character or, again, leading to the production of mutation.

"Granted, that is, that in its brood lines we have come to realize

the mode of constitution of the proteidogenous molecule and that we are justified in assuming that the biophoric or living molecules partake of similar constitution and that our conception of growth is that which must be accepted, then, under these conditions, growth, in a common medium, of biophoric molecules of two orders, alike in general constitution but differing in certain of their component chemical nuclei, must result in a certain amount of interchange of those nuclei. Two sets of biophores may still be traced in the blastomeres, in germ cells, and other cells derived from the fertilized ovum; two sets each derived by direct physical descent from the original paternal and maternal biophores and

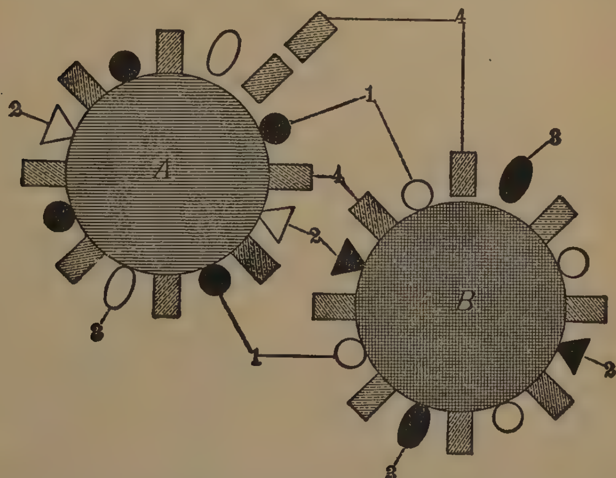


FIG. 101.—Schema of mode of interaction of two biophoric molecules in a common cell sap: *A*, of maternal; *B*, of paternal origin. 1, 2, 3, Allelomorphic side chains, which, when liberated into the cell sap, will be attracted to the biophore exercising the strongest affinity; 4, side chains common to both molecules, built up indifferently into either. (*Adami.*)

chromosomes, respectively, but the members of each of these, while building up into their structure material assimilated by their legitimate progenitors, attract for purposes of growth allelomorphic matter formed similarly by the other.

"By this method, apart wholly from what may be regarded as external influences acting upon the germ cells during their existence within the organism of the individual, it must come to pass that through conjugation the biophores giving rise to a new individual are not identical with those of either parent, and that each comes to lose certain properties which belonged to the biophores of the one and gain some belonging to the biophores of the other. If

this be so, then we can picture that in the process of reduction and casting out of biophoric material in the development both of the oocyte and of the spermatocyte, *while there are delivered to the ovum molecules of living matter which in direct descent have been derived from one parent only, those molecules may convey to the ovum constitution and properties which have been derived from both parents.* In this way, without any increase in the number of determinants or ids, by this chemical modification of biophores, a constant number of such biophoric molecules may become the bearers of properties derived from a long series of ancestors.

"We purposely do not here consider all the different types of inheritance, for this is not a full treatise upon the subject. We have taken up forms that are sufficiently wide apart to show that this biophoric theory is capable of elucidating their occurrence.

"It appears to us to have the great advantage of explaining how hereditary characters may be conveyed through a relatively small number of molecules of highly complex organization; how those molecules can in the course of amphimixis undergo modification through interaction; how they can become modified through the action both of amphimixis and of environment; how similarly they may undergo retrogressive changes and lose certain properties under the same influences.

"With reference to the action of environment on the germinal biophores it is still necessary that something be said, but our treatment of the subject of amphimixis will not be complete without reference to the remarkable reduction process that precedes fertilization. The mode of that reduction we have already described. We have seen that in the process of the maturation of the ovum, three-quarters of the chromatin present in the penultimate stage of the process is cast out (three polar bodies), one-quarter only being retained, and that similarly the spermatozoon is developed from one-quarter of the nuclear matter of the primary spermatocyte.

"As shown by the abundant recent studies on Mendelism, the results of this reduction may be very remarkable; certain properties may at a single conjunction be thrown out so completely that they do not reappear in subsequent generations.

"During the very first process of reduction in a hybrid a property or properties derived from the one parent may thus be thrown out; and yet when the parents had differed in several particulars, at this same moment properties derived from the other parent may likewise disappear. And as in such hybridization there may be as many as a score of properties in which the two parents had been contrasted—size, color of flower, position of flowers, shape of leaf, hairiness of leaves, shape of seed, etc.,—the process of sorting prior to this casting out, if we regard these qualities as conveyed by distinct ids or determinants, is beyond conception. It demands so exact a localization in each chromosome of the particular determinants, and at the same time so precise a distribution of the determinants for the various properties, that by no possible means have we been able to visualize what is supposed to happen. By the biophoric concept this casting-out process is,

we think, comprehensible, namely, as has already been stated, we can imagine that during the sojourn together of the parental biophores in the germ cells of the new individual, from the moment of fusion of the parental germ plasms to give rise to that individual,

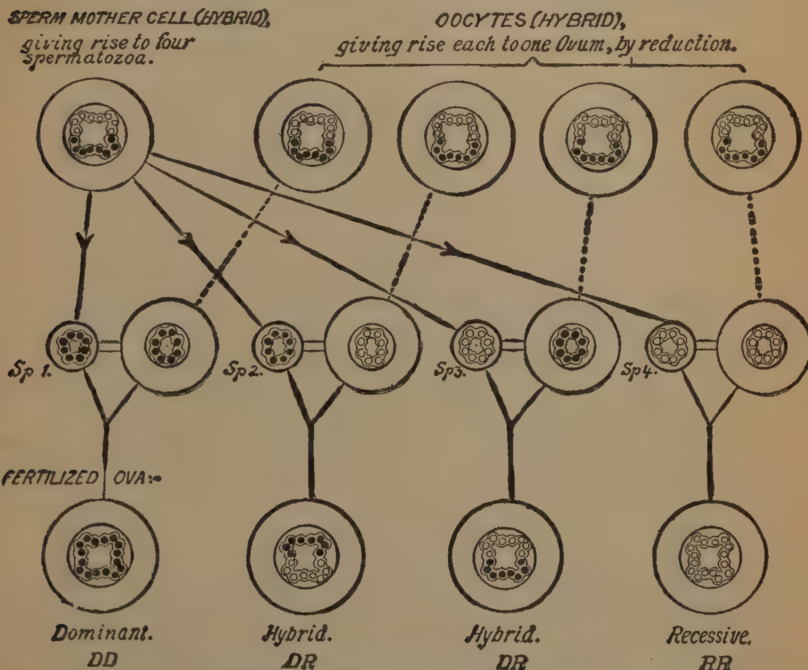


FIG. 102.—Schema to illustrate Mendel's law regarding the second hybrid generation as regards a single pair of features, as also to illustrate the effects of reduction of the chromosomes in oogenesis and spermatogenesis.

Each germ cell (first row) is originally provided with chromosomes of paternal (black) and of maternal origin (white). The existence of the law demands that in the process of reduction the ovum and the spermatozoon (second row) become provided with chromosomes (and biophores) that are of either paternal or of maternal descent, but not of both; although, as above noted, the biophores may in their growth and development have attracted side chains formed primarily by the opposed order of biophores, to the exclusion of those originally belonging to them. (*Adami.*)

up to the maturation of his or her germ cells, there is an interaction and interchange between the side chains to whose presence is due these contrasted features, and this of such a nature that the newly developed biophores, descended, let us say, from the biophores

of the female parent, have not the identical composition of those parental biophores. In the process of growth and formation there has been, as it were, a selective process.

"Owing to the greater affinities, they have attracted and built unto themselves certain side chains derived from the paternal biophores, and from merely attracting them in the first place, they have come to form them actively. According to our conception, that is, a side chain, to whatever central ring it is attached, tends to attract ions and radicals of a particular order to itself, so as to reproduce itself in series. This interchange depending upon chemical affinities will not be universal, affecting all the side chains of both paternal and maternal biophores; the newly formed biophores will present an admixture of the two orders; they will occupy definite positions in the nuclear thread and in the chromosomes derived from that thread.

"Thus it will happen that in the process of reduction, as indicated by the studies upon hybridization, the maturing ovum, or the spermatozoon, may come to contain biophores of paternal or purely maternal origin. The accompanying diagram indicates what we conceive to be the process.

"Along these lines we believe it is possible to conceive the conveyance of a limited number of biophores in the germ cells, from generation to generation, those biophores under favorable conditions gaining through amphimixis accretions to their properties, under favorable conditions becoming shorn of certain properties, and as a result the individuals developing from these germ cells may show either progressive evolution or devolution."

References.

Herbert Spencer: "Principles of Biology," 1864, N. Y., 1891.

Charles Darwin: "The Variation of Animals and Plants under Domestication," New York, 1897

Francis Galton: "A Theory of Heredity," Jour. of the Anthropological Institute, 1875. "Hereditary Genius," N. Y., 1870. "Inquiry into the Human Faculty."

August Weismann: "The Germ Plasm," N. Y., 1898.

W. K. Brooks: "The Laws of Heredity," etc., Baltimore, 1883.

Gregor Johann Mendel: "Versuche über Pflanzenhybriden," 1865. Translation published in the Journal of the Royal Horticultural Society of London, 1901–2.

W. Bateson: "Mendel's Principles of Heredity," Cambridge, 1902.

Yves Delage: "L'hérédité et les grandes problèmes de la biologie," Paris, 1903.

R. C. Punnett: "Mendelism," Cambridge, 1909.

Robert Heath Lock: "Recent Progress in the Study of Variation, Heredity and Evolution," London, 1909.

CHAPTER XI.

DIVERGENCE.

The classification or orderly arrangement of living things according to structural simplicity and complexity seems to have been early followed by the deduction that the simpler forms appearing first, the complex forms descended from them by *evolution*. Such ideas are very old and can be found in the Greek philosophy of nearly two thousand five hundred years ago.

Anaximander of Miletus (B. C. 611), his disciple Anaximenes (528 B. C.), Heraclitus of Ephesus, Pythagoras of Samas (B. C. 582), Parmenides of Elea (B. C. 515) and Empedocles of Agrigentum (B. C. 500 (?)), all busied themselves with cosmical speculation and offered various evolutionary hypotheses for the genesis of our planet. Empedocles went a step farther and speculated upon the origin of the living beings that people the earth. He believed that "plants first sprang from the earth while the latter was still in process of development. After them came the animals, their different parts having first formed themselves independently and then been joined by love; subsequently the ordinary method of reproduction took the place of this original generation. At first eyes, arms, etc., existed separately; as the result of their combination arose many monstrosities which perished; those combinations which were capable of subsisting, persisted and propagated themselves."

Aristotle of Stageiros in Thrace (384 B. C.), the first of the physiologists, taught vaguely that there was a gradual succession of life forms from the less to the more perfect, but seems to have believed that they were separate creations.

With the coming of the Christian faith speculation upon the ultimate cause of things, their mode of origin and the order of their succession became lost through the acceptance of the Jewish cosmogony which represented the world and all its organized beings as having been created by Yehwe (Jehovah) in the six creation days.

St. Augustine (A. D. 354–430) entertained a philosophical conception of creation that probably grew out of his early Manichean education, and speaks of the "creation of things by a series of causes." Thomas Aquinas (1226–74) recalled St, Augustine's teaching and upheld it, but the "creation" became a dogma of the Church and interrupted scientific thought and investigation for many centuries.

In tracing the history of the evolutionary hypothesis it is most interesting to observe that it reappeared in the Middle Ages, as it primarily appeared among the Greeks, in the writings of the philosophers and not in those of the naturalists. Thus the German philosopher, Leibnitz, (1646–1716) conceived that living beings form an unbroken series from the simple to the complex, some steps in the series having become extinct. He also conceived that individual forms underwent change as the result of the action of external forces, and believed that Nature was progressive and ever advancing. The advance is, however, slow, hence his dictum, "*Natura non facit saltum.*"

Thoroughly imbued with the teachings of Leibnitz, Buffon (1707–88) continued and enlarged the thought. He believed that organisms could be modified by changes in climate, food, and domestication, and also that parts could be modified by disuse. He also held that all animals might be derived from a single type.

The philosopher David Hume thought that "the world might have been gradually produced from very small beginnings, increasing by the activity of its inherent principles rather than by a sudden evolution

of the whole by the almighty fire. What a magnificent idea of the infinite power of *The Great Architect!* The Cause of causes. Parent of parents. *Ens entium!*"

"De Maillet, writing in 1753, appears to have been convinced that existing species of animals arose through modification of their predecessors. At the beginning of the nineteenth century similar speculations were published by Goethe and by Treviranus, the latter having been the first to apply the term 'Biology' to the science of the phenomena of life."

Erasmus Darwin (1731–1802), an English physician and naturalist, wrote upon evolution, embodying his ideas in two chief works, "The Botanic Garden" (1789), and "Zoonomia" (1794–6). He believed that "all animals have originated from a single 'living filament'; that changes are produced by differences of climate; that all animals undergo constant changes, and that many of their acquirements are transmitted to their posterity; that the contests of the males for the possession of the females lead to such results as have since been stated under the name of 'sexual selection'; that many structures have been acquired as a means of security in a struggle for existence; and that a vast length of time has elapsed since these modifications began."

Following Buffon, who was his personal friend and greatly influenced him, came the first of the modern evolutionists, Jean Baptiste Pierre Antoine de Monet de Lamarck (1744–1829), well-educated, a capable and versatile naturalist, well versed in botany and zoology. He greatly improved the classification of animals, being the first to separate vertebrates and invertebrates and introduced many new orders into the classification. He was the first important invertebrate paleontologist, and may be credited with having founded that department of science. It was as a paleontologist that he was brought into opposition with Cuvier (1769–1832) who believed in the sudden creation and extinction of species. Lamarck believed that the fossil forms of life were the

ancestors of the forms now living. The principles to which he adhered were: "1. The great length of geological time; 2. The continuous existence of organic life throughout all the geological periods; 3. The general similarity of the physical environment throughout the periods; 4. Continual gradual changes without cataclysms or catastrophic destruction of life; 5. Gradual modifications in the living things to correspond with the environment; 6. Gradual modifications of the habits to coincide with the gradual changes in structure."

Lamarck believed that all living things arose from germs that developed spontaneously, and that the most simple of these was "monad-like." The first germs of animal and vegetable life were formed in favorable places and under favorable conditions. The functions of life beginning and an organic movement being established, these germs "necessarily gradually developed into organs so that after a time and under suitable circumstances they have been differentiated" into different parts or organs, development proceeding from the simple to the complex. The time during which such differentiations have been in progress is "absolutely beyond the power of man to appreciate in an adequate way," but "With the aid of sufficient time, of circumstances which have necessarily been favorable, of changes of condition that every part of the earth's surface has successively undergone—in a word, by the power which new situations and new habits have of modifying the organs of living beings—all those which now exist have been gradually formed as we now see them."

In the progress of evolution certain factors were looked upon as essential; these are now known as Lamarckian factors and are:

1. "Favorable circumstances attending changes of environment, soil, food, temperature, etc., supposed to act directly in the case of plants, indirectly in the case of animals and man.

2. "Needs, new physical wants or necessities induced by the changed conditions of life. Lamarck believed that change of habits may lead to the origination or modification of organs; that

changes of function also modify or create new organs. By changes of environment animals become subjected to new surroundings, involving new ways and means of living. Thus, certain land birds, driven by necessity to obtain their food in the water, gradually assumed characters or structures adapting them for swimming, wading, or for searching for food in the shallow water, as in the case of the long-necked kinds.

3. "Use and disuse. To use an organ is to develop it; not to use it is to eventually lose it. The anterior limbs of birds became capable of sustained flight through use; the hind limbs of whales are lost through disuse, etc.

4. "Competition. Nature takes precautions not to overcrowd the earth. The stronger and larger living things destroy and devour the smaller and weaker. The smaller multiply very rapidly, the larger slowly. A physiological balance is maintained.

5. "The transmission of acquired characters. The advantage gained by every individual as the result of the structural changes resulting from use or disuse are handed down to its descendants who begin where the parent leaves off, and so are able to continue the progression or retrogression of the character.

6. "Cross-breeding. 'If when any peculiarities of form or any defects whatsoever are acquired, the individuals in this case always pairing, they will produce the same peculiarities, and if for successive generations confined to such unions, a special and distinct race will then be formed. But perpetual crosses between individuals which have not the same peculiarities of form result in the disappearance of all the peculiarities acquired by the particular circumstances.'

7. "Isolation. 'Were not men separated by distances of habitation, the mixtures resulting from crossing would obliterate the general characters which distinguish different nations.' This thought is expressed in his account of the origin of man from apes, and is not applied to living things in general."

Lamarck sums up his ideas in four laws published in his "Animaux sans Vertebres," 1815:

I. "Life, by its proper forces, continually tends to increase the volume of every body which possesses it, and to increase the size of its parts, up to a limit which brings it about."

II. "The production of a new organ in the animal body results from the supervention of a new want which continues to make itself felt, and of a new movement which this want gives rise to and maintains."

III. "The development of organs and their power of action are constantly in ratio to the employment of these organs."

IV. "Everything which has been acquired, impressed upon, or changed in the organization of individuals during the course of their life is preserved by generation and transmitted to new individuals which have descended from those which have undergone those changes."

This last law contains the principle, fundamental in his conception of evolution for which Lamarck is best known, viz.: that *acquired characters are transmitted to the offspring.*

While Lamarck was thus working in zoology and paleontology, an Englishman, Thomas Robert Malthus, was working upon social problems and evolving truths that were destined to exert a profound influence upon some who were to follow. In 1798 he published an important "Essay on the Principle of Population as it Affects the Future Improvement of Society," of which a second improved edition appeared in 1803. The truth discovered by Malthus was that population at all times has a tendency to outgrow subsistence. The population increases in geometrical progression, the means of subsistence in arithmetical progression, so that it is only starvation that keeps the population in check. The only means of preventing overpopulation is moral restraint.

The cogent reasoning in the essay resulted in the introduction of a new principle—the Malthusian doctrine—into economics and led to considerable modification in the poor-laws of England.

Lamarck's work and teachings were eclipsed by the somewhat bitter opposition as well as brilliant work of his compatriot, Cuvier, and were neglected for many years when they were revived by the Neo-Lamarckians who arose in an endeavor to refute Darwin.

In 1844, Robert Chambers published, without any name upon the title page, a little book entitled "Vestiges of the Natural History of Creation" that foreshadowed the cosmical evolution to be popularized by Herbert Spencer. The book was republished in 1846, but, though apparently widely read, met with so much opposition from religious quarters that it has almost been forgotten. "The book was not primarily designed, as many have intimated in their criticisms and as the title might be thought partly to imply, to establish a new theory respecting the origin of animate nature;

nor are the chief arguments directed to that point. The object is one to which the idea of an organic creation in the manner of natural law is only subordinate and ministrative, as are likewise the nebular hypothesis and the doctrine of a fixed natural order in mind and morals. The purpose is to show that the whole revelation of the works of God, presented to our senses and reason, is a system based on what we are compelled, for want of a better term, to call *Law;* by which, however, is not meant a system independent or exclusive of Deity, but one which only proposes a certain mode of his working."

In 1852, Herbert Spencer, the philosopher of science, deduced cosmical evolution by philosophical speculation, laid the foundation of his future great work, the "Synthetic Philosophy," and revived an interest in the subject, which, now that it was supported by a great array of scientific fact, began to take a firm hold upon the thought of his time.

But the man whose life and work are most completely identified with organic evolution is Charles Darwin (1809–82), who, having spent the early years of his life in travels, during which he had exceptional opportunities for scientific observation, and many years thereafter in patient study and experimentation, in 1859 published an epoch-making work upon "The Origin of Species by Means of Natural Selection, or The Preservation of the Favored Races in the Struggle for Life."

It is extremely interesting to note that at the very time at which Darwin was engaged upon this work and had explained it to his friends, to whom some of the sheets were shown or read, another was working in the same field in much the same way and anticipated him in the publication. This was Alfred Russell Wallace, another English naturalist, who, curiously enough, had traveled over much the same ground that Darwin had covered and described in his book, " Voyage of a Naturalist in H. M. S. Beagle," and then continued his travels to the East Indies. In September, 1855, he published

an essay "On the Law which has Regulated the Introduction of New Species." In February, 1858, he wrote a famous essay "On the Tendency of Varieties to Depart Indefinitely from the Original Type." The appearance of this essay led to the publication of a preliminary essay by Darwin, and the papers of both authors were published in the Proceedings of the Linnean Society of London, August, 1858. To the credit of Darwin it should be said that, finding himself anticipated by a friend, he expressed his complete willingness to withdraw from the field, but was dissuaded from pursuing this course by the friends who knew the wealth and value of the material he had collected. Wallace parallels Darwin in discussing the nature of varieties, the struggle for existence, the law of perpetuation, of useful and useless variations, and the partial reversion of domesticated varieties, but though his writings contain the same fundamental thoughts, Wallace did not support them with the cogency and thoroughness of Darwin and so has been eclipsed by the greater light.

Darwin taught that the origin of species depends upon two chief factors, which he calls "*natural selection*" and "*sexual selection*." The former, which he describes as the "*struggle for existence*," he finds to be identical with Herbert Spencer's doctrine of the "*Survival of the fittest.*"

Darwin begins by a consideration of the various "breeds" of domestic animals and shows that from a few primitive stocks the many varieties of domestic animals have been cultivated by *artificial selection*. He points out that among animals there are slight variations in the direction of desirability and undesirability, and that by carefully conserving the desirable and eliminating the undesirable, man has been able to produce the various kinds of cattle, sheep, hogs, horses, dogs, rabbits, fowls, pigeons, etc., so well known to us. If it is to be conceived that natural selection is analogous to artificial selection, it is first necessary to admit that living things

of the same kind vary under natural conditions. Concerning this, he says:

"The many slight differences which appear in the offspring from the same parents, or which it may be presumed have thus arisen, from being observed in the same locality, may be called individual differences. No one supposes that all the individuals of the same species are cast in the same actual mould. These individual differences are of the highest importance to us, for they are often inherited, as must be familiar to everyone; and they thus afford materials for natural selection to act on and accumulate in the same manner as man accumulates in any given direction individual differences in his domesticated productions."

"I look at individual differences, though of small interest to the systematist, as of the highest importance for us, as being the first steps toward such slight varieties as are barely thought worth recording in works on natural history. And I look at varieties which are in any degree more distinct and permanent as steps toward more strongly marked and permanent varieties; and at the latter as leading to sub-species, and then to species. The passage from one stage of difference to another may, in many cases, be the simple result of the nature of the organism and of the different physical conditions to which it has long been exposed; but with respect to the more important and adaptive characters, the passage from one stage of existence to another may be safely attributed to the cumulative action of natural selection, hereafter to be explained, and to the effects of the increased use or disuse of parts. A well-marked variety may therefore be called an incipient species; but whether this belief is justifiable must be judged by the weight of the various facts and considerations to be given throughout this work" [Origin of Species].

"Varieties cannot be distinguished from species—except, first, by the discovery of intermediate linking forms; and, secondly, by a certain indefinite amount of difference between them for two forms, if differing very little, are generally ranked as varieties, notwithstanding that they cannot be closely connected; but the amount of difference considered necessary to give to any two forms the rank of species cannot be defined."

"I must make a few preliminary remarks to show how the struggle for existence bears on natural selection. It has been seen . . . that among organic beings in a state of nature there is some individual variability; indeed I am not aware that it has ever been disputed. It is immaterial for us whether a multitude of doubtful forms be called species or sub-species or varieties . . . if the existence of any well-marked varieties be admitted. But the mere existence of individual variability, and of some few well-marked varieties, though necessary as the foundation for this work, helps us but little in understanding how species arise in nature."

"If under changing conditions of life organic beings present individual differences in almost every part of their structure, and this cannot be disputed; if there be, owing to their geometrical

rate of increase, a severe struggle for life, at some age, season or year, and this certainly cannot be disputed; then, considering the infinite complexity of the relations of all organic beings to each other and to their condition of life, causing an infinite diversity of structure, constitution and habits, to be advantageous to them, it would be a most extraordinary fact if no variations had ever occurred useful to each being's own welfare, in the same manner as so many variations have occurred useful to man. But if variations useful to any organic being ever do occur, assuredly individuals thus characterized will have the best chance of being preserved in the struggle of life; and from the strong principle of inheritance these will tend to produce offspring similarly characterized. This principle of preservation, or the survival of the fittest, I have called natural selection."

"It leads to the improvement of each creature in relation to its organic and inorganic conditions of life; and consequently, in most cases, to what must be regarded as an advance in organization. Nevertheless, low and simple forms will long endure if well fitted for their simple conditions of life. Natural selection, on the principle of qualities being inherited at corresponding ages, can modify the egg, seed, or young as easily as the adult. Among many animals sexual selection will have given its aid to ordinary selection by assuring to the most vigorous and best adapted males the greater number of offspring. Sexual selection will also give characters useful to the males alone in their struggles or rivalry with other males; and these characters will be transmitted to one sex or to both sexes, according to the form of inheritance which prevails."

"But we have already seen how it [natural selection] entails extinction; and how largely extinction has acted in the world's history geology plainly declares. Natural selection also leads to divergence of character; for the more organic beings diverge in structure, habits, and constitution, by so much the more can a large number be supported on the area, of which we see proof by looking to the inhabitants of any small spot and to the productions naturalized in foreign lands. Therefore, during the modification of the descendants of any one species, and during the incessant struggle of all species to increase in numbers, the more diversified the descendants become, the better will be their chance of success in the battle for life. Thus the small differences distinguishing varieties of the same species, steadily tend to increase, till they equal the greater differences between species of the same genus, or even of distinct genera."

"It is the common and widely diffused and widely ranging species belonging to the larger genera within each class, which vary most; and these tend to transmit to their modified offspring that superiority which now makes them dominant in their own countries. Natural selection, as has just been remarked, leads to divergence of character and to much extinction of the less improved and intermediate forms of life. On these principles, the nature of the affinities and the generally well-defined distinctions between the innumerable organic beings in each class throughout the

world, may be explained. It is a truly wonderful fact—the wonder of which we are apt to overlook from familiarity—that all animals and all plants throughout all time and space should be related to each other in groups, subordinate to groups, in the manner which we everywhere behold—namely, varieties of the same species most closely related, species of the same genus less closely and unequally related, forming sections and sub-genera, species of distinct genera much less closely related and genera related in different degrees, forming sub-families, families, orders, sub-classes and classes. The several subordinate groups in any class cannot be ranked in a single file, but seem clustered round points, and these round other points, and so on in almost endless cycles. If species had been independently created, no explanation would have been possible of this kind of classification; but it is explained through inheritance and the complex action of natural selection, entailing extinction and divergence of character as we have seen."

"The affinities of all the beings of the same class have sometimes been represented by a great tree. I believe this simile largely speaks the truth. The green and budding twigs may represent existing species, and those produced during former years may represent the long succession of extinct species. At each period of growth all the growing twigs have tried to branch out on all sides, and to overtop and kill the surrounding twigs and branches, in the same manner as species and groups of species have at all times overmastered other species in the great battle for life. The limbs, divided into great branches, and these into lesser and lesser branches, were themselves once, when the tree was young, budding twigs; and this connection of the former and present buds by ramifying branches may well represent the classification of all extinct and living species in groups subordinate to groups. Of the many twigs which once flourished when the tree was a mere bush, only two or three, now grown into great branches, yet survive and bear the other branches; so with the species which lived during long past geological periods, very few have left living and modified descendants. From the first growth of the tree many a limb and branch has decayed and dropped off; and these fallen branches of various sizes may represent those whole orders, families and genera which have now no living representatives and which are known to us only in a fossil state. As we here and there see a thin, straggling branch springing from a fork low down in a tree, and which by some chance has been favored and is still alive on its summit, so we occasionally see an animal like the Ornithorhynchus or Lepidosiren, which in some small degree connects by its affinities two large branches of life, and which has apparently been saved from fatal competition by having inhabited a protected station. As buds give rise by growth to fresh buds, and these, if vigorous, branch out and overtop on all sides many a feebler branch, so by generation I believe it has been with the great Tree of Life, which fills with its dead and broken branches the crust of the earth, and covers the surface with its ever-branching and beautiful ramifications."

As Mr. Darwin says in the last chapter of the "Origin of Species": "This whole volume is one long argument." It is, therefore, difficult to give it the force it should convey either through a series of excerpts, such as has been here presented, or by any brief synopsis of its contents. To read the book is to become impressed by the worth of the argument as well as by the great array of carefully chosen facts that have been collected in its support. Its appearance was followed by an enthusiastic reception, and the theory of natural selection is still the source of much careful examination and experimentation.

In conclusion Mr. Darwin makes the following statement: "I am convinced that natural selection has been the main but not the exclusive means of modification."

In one of the excerpts given above this language is used: "But if variations useful to any organic being ever do occur, assuredly individuals thus characterized will have the best chance of being preserved in the struggle of life; and from the strong principle of inheritance these will tend to produce offspring similarly characterized."

If the readers of Darwin had followed his text as carefully as they should, some of the errors regarding his opinions might have been escaped. It is quite clear that he believed natural selection to be "*the main, but not the exclusive means of modification*," and it is equally evident that the general statement that his theory hinges upon the "transmission of acquired characters" is doubtfully correct. The theory really treats of the *preservation of useful*, and the *elimination of useless characters* and the characters themselves appear or disappear *spontaneously*—*i.e.*, as the result of the natural tendency of living things to vary.

The first effect of Darwin's work was to carry the world of science by storm, but at the same time to arouse intense hostility on the part of the theologians who found the theory of descent, which, as has been shown,

did not originate with Darwin, incompatible with the doctrine of Creation. In this conflict, Darwin took little part, but was championed by Huxley, while Bishop Wilberforce led the opposition. The battle was long and bitter, there was much acrimonious writing on both sides, but the theory of descent—the doctrine of evolution—was found to be invulnerable and at present the theologians themselves have accepted it and even make use of it in their own work.

But as the years flew by the Darwinian doctrines began to meet with assaults from the scientists themselves who having endeavored to prove their validity began to find them inadequate to the requirements of expanding knowledge. The question was asked, "What is the origin of the fittest?" Given the fittest, we easily understand how it is perpetuated, but how does it arise? Can the specific beginnings be found in the principle of natural selection? Gradually the ranks broke and scientists of distinction—von Baer, von Kölliker, Virchow, Nageli, Wigand, Hartmann, von Sachs, Eimer, Delage, Haacke, Kassowitz, Cope, Haberlandt, Coethe, Wolff, Driesch, Packard, Morgan, Jaeckel, Steinmann, Korchinsky, and De Vries—broke away declaring that the origin of species was not to be found in Darwinism, and returned to the teachings of Lamarck, that inherited acquired characters formed the inception of the specific differences (Neo-Lamarckism).

This must not be interpreted, however, to mean that Darwinism was dead. Indeed there was soon a *Neo-Darwinism* revival with a goodly following, at the head of which stood Weismann.

Weismann's doctrine of the "inviolability of the germplasm" as first expressed appeared to be opposed to Darwin, for it argued that nothing could appear in the offspring that was not already present in the germ plasm, hence no condition to which an organism was subjected could modify its descendants, seeing that the germ plasm from which they were to

descend was already in being. But, as has already been shown in discussing the theory in the chapter dealing with the problems of inheritance, Weismann was later obliged to modify the theory and to admit that the germ plasm can and does become modified through residence in its host. Such a conclusion was inevitable; amphimixis, or the commingling of different germ plasms, could never account for divergence, seeing that originally the germ plasm was all the same. If the germ plasm is susceptible of modification, as Weismann himself admits and we must conclude, such modifications are undoubtedly governed by forces acting upon the germ plasm while in the host, and hence probably by conditions to which the host is subjected. This is perfectly in accord with Darwin and made Weismann one of the strongest of the Neo-Darwinians.

The Neo-Lamarckians, however, including Herbert Spencer, Packard, Osborn, Eimer, among their early champions, carried on a bitter warfare, and many interesting phases of the subject were discussed during 1893 and 1894 in papers by Herbert Spencer on the one side and Weismann on the other.

The question at issue has never been settled. There are present-day scientists who see no reason why natural selection may not account for the origin of species, there are others to whom it is totally inadequate. Indeed, one scientist, Korschinsky, takes a diametrically opposed view and appears as the most radical anti-Darwinian, with the following expressions regarding natural selection:

"The origin of new forms can only occur under conditions favorable to them, and the more favorable such conditions are, that is, the less severe the struggle for existence is, the more energetic is their development. Under severe external conditions new forms do not arise, or if they appear they are extinguished.

"The struggle for existence, and the selection which goes hand in hand with it, compose a factor which restricts new appearing forms and restrains wider variations, and which is in no way favorable to the production of new forms. It is, indeed, an inimical factor in evolution.

"Were there no struggle for existence, then there would be no extinguishing of arising or already new forms. The organic world

could then develop into a mighty tree, whose branches could all remain in blooming condition, so that the now isolated extremest species would be united with all others through gradatory forms.

"The adaptation resulting from the effects of the struggle for existence is absolutely not identical with advance for higher standing; more complex forms are by no means always better adapted to outward conditions than the lower ones. The evolution [here used by the author as synonymous with advance or progressive complexity] of organisms cannot be explained in a purely mechanical way. In order to explain the origin of higher forms from lower forms it is necessary to postulate in the organisms a special tendency to advance which is nearly related to, or identical with the tendency to vary, which tendency compels the organisms to advance so far as the outward conditions permit."

It may be wise to add that such views have not met with acceptance even among the most urgent anti-Darwinians.

In endeavoring to account for the origin of species otherwise than by natural selection, De Vries, a strong anti-Darwinian, has advanced the theory of *Mutation*. This Belgian botanist had the good fortune to discover a plant, *Œnothera lamarkiana*, a variety of primrose, at a time when it appeared to undergo a sudden transformation, diverging from its customary type to a larger and quite different one. The new form, which differed sufficiently to constitute a new variety, if not a new species, appeared to undergo the change "spontaneously," *i.e.*, without any accountable cause. It was, in other words, a "sport" of Nature. The new individual, however, bred true, without any tendency to revert to its original type, and has remained true. This has led De Vries to the conclusion that new species arise spontaneously as "freaks" or "sports," and that such new forms appear infrequently in the history of every species and serve as points of departure from the old type. According to this theory, which seems to be widely accepted by scientists of the present day, species arise suddenly, by mutation, and not gradually by natural selection. De Vries showed quite clearly that there was a distinct difference between the fluctuating and non-heritable variations that are but varieties and the permanent

and heritable variations to which he applies the term *mutation*.

It should be said, however, that examples of such sudden mutation are very infrequent, and that some of them were known to Darwin, as, for example, the Ancon sheep.

The scientists of to-day are fully in accord that all the living things we know have become diversified by evolution from antecedent and simpler forms, and these from antecedent simpler forms until we are eventually brought back to the primordial protoplasm. There is no controversy as to *what* has taken place, the question at issue is *how* it has come about. The further back we go, the more difficult the question becomes. We cannot imagine the nature of the first distinctly living organisms. As they must have been of very soft substance and derived their support from substances of inorganic nature uniformly diffused through some fluid medium, we are probably correct in supposing that they were aquatic and marine. Through what forces this elementary substance began its primary differentiations is not known. It would at first glance seem to be removed from every outside influence and, therefore, unlikely to be either modifiable or modified; but on second thought one remembers that the ocean is not uniform in its conditions. It reaches to the poles where it is cold, it crosses the equator where it is warm; through it streams of warmer or colder water flow; into it rivers of fresh water empty; in it various substances dissolve; its shores, which form a solid sub-stratum, are washed by breakers; its surface is touched by the sun, its depths are in perpetual darkness. Surely, under these diversified conditions living substance if modifiable would find conditions appropriate for modification. Indefinite time must have elapsed before the first step was taken, great periods of time must have elapsed before differences became pronounced; but once started, the process of differentiation and diver-

sification progressed in the sea and later on the land until the world of to-day arrived.

The vastness of time necessary for the evolutionary phenomena was at first supposed to be one of the strongest arguments against it, for the astronomers and geologists found it impossible to admit the age of the world's crust to be sufficient to permit them. But this objection has been effaced, for the discovery of radium by which the sun makes good its heat loss and the further discovery that the earth possesses self-sustaining heat centres and is not entirely dependent upon the sun for its supply have upset all past calculations in cosmogonics and now permit the biologists almost infinite time for evolution.

But granting the process of evolution in progress, by what means does it continue? By a succession of fits and starts, leaps and bounds, or by a series of continuous and almost imperceptible changes, or does it do so by means of both?

References.

Charles Darwin: "The Origin of Species by Means of Natural Selection." "The Descent of Man." "The Variation of Animals and Plants under Domestication."

Herbert Spencer: "First Principles." "Principles of Biology."

E. D. Cope: "The Origin of the Fittest," N. Y., 1887. "The Primary Factors in Organic Evolution," Chicago, 1896. "The Origin of Genera," 1868.

George John Romanes: "Darwin And After Darwin," Chicago, 1896.

Ernst Haeckel: "The Riddle of the Universe," Translated by Joseph McCabe, N. Y., 1900. "The History of Creation."

Thomas H. Huxley: "Man's Place in Nature," and other Essays.

Robert Chambers: "Vestiges of the Natural History of Creation," London, 1887.

Hugo De Vries: "Species and Varieties, their Origin by Mutation," Chicago, 1906.

Vernon S. Kellogg: "Darwinism To-day," N. Y., 1908.

F. W. Hutton: "Darwinism and Lamarckism." N. Y., 1899.

W. H. Conn: "The Method of Evolution," N. Y., 1900.

Jean Baptiste Pierre Antoine de Monet de Lamarck: "Animaux sans vertebres," 1815. "Philosophie Zoölogique," 1809.

Erasmus Darwin: "The Botanic Garden," 1789. "Zoonomia," 1794–6.

Alfred Russel Wallace: "Contributions to the Theory of Natural Selection," New York and London, 1870.

Thomas Robert Malthus: "An Essay on the Principle of Population, etc.," London, 1826.

T. H. Morgan: "Evolution and Adaptation," New York, 1903.

CHAPTER XII.

STRUCTURAL RELATIONSHIP.

In the earliest Hebrew Scriptures we find living things already separated, in the minds of the writers, into such general classes as "grass," "herb yielding seed," "fruit trees yielding fruit after their kind, whose seed is in itself," "creeping things," "fish," "fowls of the air," "beasts of the field," and "man," which enabled them to be collectively mentioned, and paved the way for future more precise groupings. To these writers, however, each kind was separately created and independent of all others.

Grecian philosophical speculation concerning the origin of things found no satisfaction in the creation hypothesis, and at an early date the idea prevailed that the earth and its creatures arose in a more or less orderly sequence by process of evolution. With as much thoroughness as their familiarity with the living creatures permitted, they divided them into groups suggesting the order of descent, beginning with the most simple and ending with the most complex. These endeavors were, however, much impeded by superstitions regarding the ready spontaneous generation of almost any living thing, and the equally prevalent belief that living things of one kind readily metamorphosed into others.

The history of scientific classification seems to begin with Aristotle, who as an anatomist and physiologist acquired a broad knowledge of the lower animals and divided them as follows:

Bloodless Animals.—Insects
Molluscs
Crustacea
Testacea

Blooded Animals.—Fishes
Amphibia
Birds
Mammals

Here the matter rested for centuries without important addition or alteration, for religion displaced science and philosophy, which were almost forgotten until the Renaissance.

The next important classification comes to us from Linnæus, the father of botany and a profound thinker and reasoner. Not a versatile zoologist, but one to whom zoology owes much in the introduction of the binomial nomenclature and in the description of all the common forms of animals, he gives us the following very simple arrangement:

I. Mammalia
II. Aves
III. Amphibia
IV. Pisces
V. Insects
VI. Vermes

Linnæus thus departs from Aristotle by dispensing with the two primary divisions of Bloodless and Blooded animals.

Aristotle based the primary groupings upon the presence or absence of (red) blood, but we find that Linnæus abandoned this feature. This leads us to inquire what are the legitimate characters upon which classification can be based.

Such characters are purely arbitrary and at the option of the systematist by whom the classifying is done. But in the arbitrary selection of the characters used for the purpose one thing is essential, viz., that they be *constant*. They need not bear any reference to structural or functional importance, but they must be invariable. Now, when we scrutinize Aristotle's employment of the presence or absence of blood as a primary differential character, we find it to be inconstant. Blood was,

to Aristotle, a red fluid that escaped from an organism when injured. That blood owed its redness to corpuscles, and that their color in turn depended upon the quantity of hemoglobin they contained were facts beyond his power of finding out. He must have confused any other red fluid with blood had he found it. So soon as it was discovered that the redness of the blood depended upon the hemoglobin and that this substance appeared regularly and in large quantities in some of his lowest groups, the differential value of the character was lost. What is true of Aristotle's may be true of any differential factor in classification—with expanding knowledge its validity may be destroyed. The problem of the systematist is to find the invariable characters and build upon them.

The purpose of classification may differ, and therefore the means may also differ. The earliest classifications were supposed to partake of the nature of a family tree and were based upon the supposition that the higher forms of existing animals arose from the lower forms by some more or less direct mutation.

Ancient observers had not overlooked the fact that bones and teeth of extraordinary size and remarkable shape were found here and there upon the earth's surface, and that beds of marine shells were sometimes to be found upon the uplands and in the mountains. These puzzling circumstances were generally accounted for upon the supposition that in the prehistoric times giants and chimerical monsters had inhabited the earth, and that there had been great deluges when the sea arose and covered the highest mountain tops. Myths to account for such things are to be found among all nations. Later scientific scrutiny showed that these "fossil" remains for the most part resemble living creatures, though some are dissimilar. Gradually *Geology*, the study of the formation of the earth's crust, and *Paleontology*, the study of extinct forms of life, developed as special departments of investigation, receiv-

ing great progress through the labors of Lamarck, who founded the science of invertebrate paleontology, and Cuvier who founded that of vertebrate paleontology, and it was discovered that the "fossil remains" afforded an insight into the nature and structure of creatures that had long ago inhabited the earth, but became displaced by now existing forms. Fossil animals, therefore, came to require a place in the genealogical tree, or system of classification.

Should it ever become possible to become acquainted with all of the animals that have lived as well as all of those that now live, and to place them in correct and orderly position with reference to one another, the arrangement would show the exact genealogy of every group and its complete family tree.

Such a family tree would also show that the different groups of animals that we now know have not, as the early systematists imagined, developed one into the other, but that they are simply branches of the same great family tree so that to get from one to the other one would be obliged to descend one branch to some common intermediate, or even go back to the main trunk and ascend again in order to reach the new branch. This is a most fundamental conception. The various animals we now know are the newest buds and sprouts upon the apical twigs of boughs, branches, and limbs of the tree of life that has been growing and spreading ever since life first made its appearance.

The ambition of every systematist of the present time is to so arrange the known living and extinct organisms as to make them find their proper places in the *evolutionary sequence.* This is quite a different matter from that of arranging them in the order of development one into the other.

How nearly we are in a position to complete the genealogical tree may be judged by a hasty comparison of the known living and fossil forms. Allowing a liberal margin for error, it may be surmised that there are known

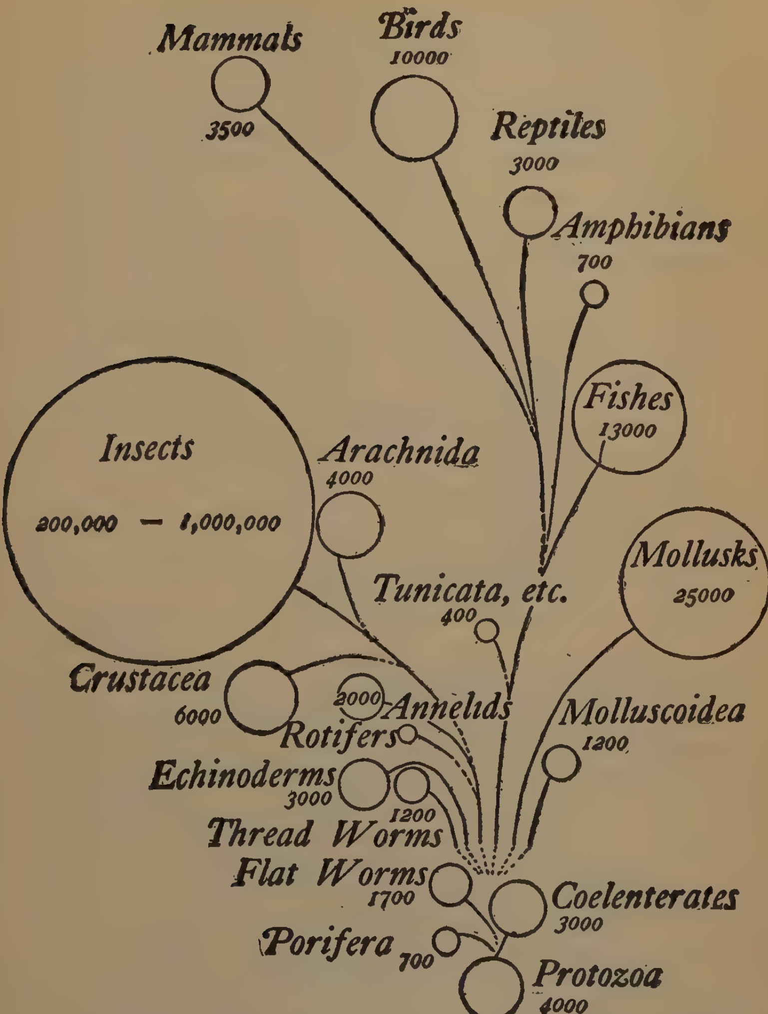


FIG. 103.—Diagram showing the general relations of the chief divisions of the animal kingdom. The number of species belonging to each is roughly approximate only. (*Galloway.*)

at the present time not less than 500,000 different species of living animals and about 75,000 different species of fossil animals. Reflection upon the conditions of evolution considered in another chapter should convince one that the number of species now living must be infinitesimal compared with the great number of extinct forms from which they have descended and to which they are related. In consequence the genealogical tree is deficient in many of its parts which can be linked together only in imagination. Some of these gaps can, and no doubt will, be filled in time by the discovery of additional fossil species, but many of them, embracing soft-bodied animals that leave no relics behind them, can never be filled in.

An important improvement in classification came from the great French naturalist, Cuvier (1798). The chief divisions are as follows:

Branch I.—Animalia Vertebrata:
- Class 1. Mammalia
- 2. Aves
- 3. Reptilia
- 4. Pisces

Branch II.—Animalia Mollusca:
- Class 1. Cephalopoda
- 2. Pteropoda
- 3. Gasteropoda
- 4. Acephala
- 5. Brachiopoda
- 6. Cirrhopoda

Branch III.—Animalia Articulata:
- Class 1. Annelides
- 2. Crustacea
- 3. Arachnides
- 4. Insects

Branch IV.—Animalia Radiata:
- Class 1. Echinoderms
- 2. Intestinal worms

3. Acalephæ
4. Polypi
5. Infusoria

In 1801, Lamarck introduced a new term—"Invertebrata"—and a new idea, that of physiology, into classification; he also made a revision of Cuvier's classification, leaving the vertebrates unchanged.

Invertebrata.

I. Insensitive Animals—Class 1. Infusoria
2. Polypi
3. Radiaria
4. Tunicata
5. Vermes

II. Sensitive Animals—Class 6. Insects
7. Arachnids
8. Crustacea
9. Annelids
10. Cirripeds
11. Conchifera
12. Mollusks

Vertebrata.—Class 13. Pisces
14. Reptilia
15. Aves
16. Mammals

The employment of function as the correlative of structure in classifying animals was overdone by Oken, who, in 1810, published the following classification of the Invertebrates:

Grade I.—Intestinal Animals.

Cycle I. Digestive Animals—Radiata
Class 1. Infusoria (stomach animals)
2. Polypi (intestine animals)
3. Acalephæ (lacteal animals)

Cycle II. Circulative Animals—
Class 4. Acephala (biauriculate animals)
5. Gasteropoda (uniauriculate animals)
6. Cephalopoda (bicardial animals)

Cycle III. Respirative animals—
7. Worms (skin animals)
8. Crustacea (branchial animals)
9. Insects (tracheal animals)

A new idea followed the active pursuit of embryology by the German naturalists and is expressed by von Baer, whose idea that "ontogeny recapitulates phylogeny" led him to propose the following classification based upon the embryological development of the members of the various groups:

I. Peripheral type (Radiata)
II. Massive type (Mollusca)
III. Longitudinal type (Articulata)
IV. Doubly symmetrical type (Vertebrata)

"Thus, von Baer, with his classification, based on embryological principles, and Cuvier, with his, founded on comparative anatomy, arrived at very similar conclusions, viz.: that animals are built upon four general plans and fall into four general groups. In the end, the system of Cuvier triumphed over that of the natural philosophers."

Revisions of the classification of the invertebrata were published by Agassiz and later by Huxley and did much to assist in promoting research upon the animals of these divisions. As, however, their classifications were not based upon any essentially new idea, it seems proper to pass on to the modern classification.

According to the plan adopted at present, the whole animal kingdom is divided into two *Sub-divisions*, the Protozoa and the Metazoa. Each sub-division is made up of certain grand groups or *Phyla* which represent more or less well-marked *plans* of *structure*, and form the points about which all the animals constructed upon a similar general plan are arranged. Each phylum includes a number of *Classes*, each of which is composed of organisms which, though phyletically related, differ in some constant feature, such as having six legs or

eight legs, etc. Each class, in turn, is composed of *Orders* into which closely related *Families* fall, and each family is composed of *Genera*, which in turn embrace the smallest groups or *Species*.

Each group is arbitrary, but the characters upon which the larger groups are founded have been shown by experience to be so constant as to permit of little present modification. The changing groups are the families, genera, and species, and of these the genera and species are subject to the greatest mobility. There is no fixed opinion as to what shall constitute a species or what shall be called a *variety* of a species. In groups of organisms much studied specific differences are so minute that only the most careful scrutiny with the microscope can discover them; in groups little studied the species differ quite as widely as the genera of much studied groups.

Cuvier tried to make the criterion of specific differentiation the tendency of the organism to *breed true*, but as the breeding of vast numbers of organisms is something concerning which no information is available and upon which none may be attainable, it becomes impossible to follow the suggestion.

According to the general acceptation, a species is composed of individual organisms whose dissimilarities are so slight and inconstant as not to be definite. Many think that specific differences should be structural only; others admit differences of coloration as marks of specific differentiation. Those who base specific characters upon structural differences alone, separate similarly constructed but differently colored or different-sized organisms into still lower groups known as *varieties*. Varieties, however, may differ among themselves in structure as species sometimes do. Thus, among the barnyard fowls the rose comb and the toothed comb and the presence or absence of spurs are well-marked structural differences, yet are not looked upon as specific, and no one can gainsay that there are structural differences between the bull-dog, the greyhound, and the

dachschund, though all dogs are regarded as of the same species.

Specific grouping is, therefore, chiefly a matter of personal equation with the systematist. Fortunately, it has little or no practical importance in the general plan of classification.

At this point it may be well to digress and say a few words about the *binomial nomenclature* of Linnæus, which has now been adopted by international agreement among scientific men. Experience has shown that in naming men but small confusion occurs when each individual receives two names. Thus John Smith is understood to be a member of the Smith family individually known as John. As, however, the Smith family is large, and John is a favorite name, there may be several individuals known as John Smith. Such confusion rarely arises, however, in scientific nomenclature, because the name is not the designation of an *individual*, but of a *kind*. Greek and Latin names have been agreed upon for scientific nomenclature, because they are, so to speak, international languages and less likely to cause confusion than English, German, French, or Italian. For example, the common black and white hornet that builds the large rounded paper nests was described by Linnæus as *Vespa maculata*. By agreement the name of every organism is followed by the name (usually abbreviated) of the man first describing it. The name of this insect is, therefore, now written *Vespa maculata* Linn. The word *maculata* is the name of the *species* or particular kind, and is always written with a small letter, even if derived from a proper noun. Thus Megatherium cuveri, Mimisa cressoni, Bacillus welchi, etc. This specific name must be the first name applied, no matter by whom or when, and regardless of its appropriateness. The specific name is always Latin or latinized. The specific name by itself is comparatively meaningless, just as though one spoke of Clarence. Who is Clarence? What Clarence? So,

should one speak of "*maculata,*" it would mean nothing, since many species, because of their spotted character, might have received that name. When, however, one says *Vespa maculata* or *Amblystoma maculata,* it at once becomes quite clear what animal is intended. The generic name, which comes first, may be Latin, and is of all the older genera, but is now, by preference, of Greek derivation. The specific name may never change, but the generic name may have to be changed from time to time because many genera when carefully studied are found to be divisible into several new genera. When this happens, it is agreed that new generic names may be used, but that the old generic name if not continued for one of the newly formed divisions may never be employed again.

The following outlines of modern classification are introduced in order that readers not familiar with botany or zoology may secure an approximately correct idea of the general relations that living things bear to one another.

THE PLANT KINGDOM.

Phylum I.

Thallophyta. The thallus plants.

Series 1.—Algæ, unicellular forms, pond weeds, sea weeds, etc.

Class I.—Cyanophyceæ, the blue-green algæ.

Class II.—Chlorophyceæ, the green algæ.

Class III.—Phacophyceæ, the brown algæ.

Class IV.—Rhodophyceæ, the red algæ.

Series 2.—Fungi, bacteria, yeasts, moulds, smuts, mushrooms, etc.

Class V.—Schizomycetes, the bacteria.

Class VI.—Saccharomycetes, the yeasts.

Class VII.—Phycomycetes, the alga-like fungi.

Class VIII.—Ascomycetes, the sac-fungi.

Class IX.—Basidiomycetes, the basidia fungi.

Phylum II.

Bryophyta.—The moss-like plants.
Class 1.—Hepaticæ, the liverworts.
Class 2.—Musci, the mosses.

Phylum III.

Pteridophyta.—The ferns and their allies.
Class 1.—Filicineæ, true ferns.
Class 2.—Equistineæ, the horse tails.
Class 3.—Lycepodineæ, the club mosses.

Phylum IV.

Spermatophyta.—The seed-bearing plants.
Sub-division 1.—Gymnospermæ.
Sub-division 2.—Angiospermæ.
Class I.—Monocotyledons.
Class II.—Dicotyledons.

While most of the groups in this classification include forms naturally related, the algæ and fungi, respectively, include sub-groups whose relationship is doubtful. Thus, the bacteria are very likely more nearly related to certain of the algæ than to any fungi, though in habit of life they are like the latter.

THE ANIMAL KINGDOM.

Division I. Protozoa.—Unicellular animals.

Phylum—Protozoa.—Sub-phyla.—A. Gymnonomyxa (without permanent form).
B. Corticata (with permanent form).

Class I.—Rhizopoda.—Naked protoplasmic organisms with pseudopodia, without a localized oral orifice. Multiply by binary fission.

Class II.—Infusoria.—Unicellular organisms provided with cilia or flagella and having a localized oral orifice. Multiply by binary fission.

Class III.—Sporozoa. —Protoplasmic organism usually naked without an oral orifice. Multiply by dividing into many small spores.

Division II.—Metazoa.—Multicellular animals.

A. Without true cœlomic cavity—Radially symmetrical.

1. *Without a notochord—Invertebrata.*

Phylum—Porifera.

The sponges.—Characterized by many incurrent openings and only one excurrent opening. Axially symmetric. Sexually reproductive.

Class I.—Calcarea.—Skeleton of calcareous spicules.

Class II.—Non-calcarea.—Skeleton of siliceous spicules and horny fibres.

Phylum—Cœlenterata.

The jelly-fishes.—Characterized by a single mouth which also functionates as an anus. Possess stinging or nettling cells.

Class I.—Hydrozoa.
Class II.—Scyphozoa.
Class III.—Actinozoa.
Class IV.—Ctenophora.

B. With a true cœlomic cavity—Radially symmetrical.

Phylum—Echinodermata.

The star-fishes, sea-urchins, sea-cucumbers, etc.

Class I.—Asteroidea—star-fishes.
Class II.—Ophiuroidea—brittle sea-stars.
Class III.—Echinoidea — sea-urchins and sand-dollars.
Class IV.—Crinoidea—sea-lilies and feather-stars.
Class V.—Holothuroidea — sea-cucumbers.

C. With a true cœlomic cavity—bilaterally symmetrical.

Phylum—Platyhelminthes.

The unsegmented worms, etc.

Class I.—Cestoda.
Class II.—Trematoda.
Class III.—Turbellaria.

Phylum—Nemathelminthes.

Round worms, threadworms, etc.

Phylum—Molluscoidea.

Mollusk-like animals.

Class I.—Polyzoa.
Class II.—Brachiopoda.

Phylum—Trochelminthes.

The wheel animalcules or rotifers.

Phylum—Annulata.

The segmented worms.

Class I.—Chætopoda, bristle-footed worms.
Sub-class A.—Polychæta (with numerous bristles).
Sub-class B.—Oligochæta (with few bristles).
Class II.—Discophora—sucker-bearing worms.
Class III.—Archiannelida.
Class IV.—Siphunculoidæ.
Class V.—Chætognatha.

Phylum—Mollusca.

Class I.—Pelecypoda or Lamellibranchiata—mussels, oysters, and other bivalves.

Class II.—Gasteropoda—univalves or shell-less mollusks.

Class III.—Cephalopoda — squids, devil-fishes, etc.

Phylum—Arthropoda.

Jointed animals.

Class I.—Crustacea — crabs, lobsters, cray-fish, barnacles, etc.

Class II.—Onychophora—centipede-like.

Class III.—Myriapoda — centipedes, etc.

Class IV.—Hexapoda—insects.

Class V.—Arachnida—spiders, scorpions, etc.

2. *With a notochord.*

Phylum—Chlordata.

Sub-phylum I.—Atriozoa.

Class I.—Urochordata (Tunicata).

Class II.—Cephalocordata (Amphioxus).

Sub-phylum II.—*Vertebrata.*

Class I.—Pisces—fishes.

Class II.—Amphibia (Batrachia)—frogs, toads, salamanders.

Class III.—Reptilia—lizards, crocodiles, alligators, tortoises, snakes.

Class IV.—Aves—Birds.

Class V.—Mammalia—mammals.

References.

"The New International Encyclopedia," N. Y., Dodd, Meade & Co., 1907.

A. T. Masterman: "Elementary Text-book of Zoology," Edinburgh, 1902.

T. W. Galloway: "First Course in Zoology," Phila., 1906.

E. Strasburger, F. Noll, H. Schenk, and G. Karsten: "A Text-book of Botany. "Third Engish edition by W. H. Lang, N. Y., 1908.

CHAPTER XIII.

BLOOD RELATIONSHIP.

It may justly be supposed that, as living things diverged morphologically, they also diverged physiologically, and indeed this fact has been dwelt upon in various relations. Thus, with reference to nutrition, we find plants agreeing in the function of constructing their protoplasm out of inorganic compounds, and animals diverging from them in the loss of this function. Aquatic and terrestrial forms of life differ in their method of absorbing oxygen and in the quantity essential to their metabolism. Salt- and fresh-water organisms differ in their tolerance to sodium chloride and other salts. Differences in diet, in function, and in metabolism continue to increase, until we find it not infrequently happening that the flesh of one animal is poisonous for another, and occasionally happening that the body juice of one animal is poisonous when introduced into another.

In this way it comes about that the body juice of almost any living being when introduced into the body of some other warm-blooded animal is capable of acting as an *antigen*. The reactions induced by these antigens vary according to the method of treatment, as will be shown in the chapter upon Infection and Immunity; but when it is administered in small doses, frequently repeated, so that no harm is effected, induces the formation of an antibody capable of precipitating it. Thus come about *Zooprecipitation* and *Phytoprecipitation*—the latter, when the juices of plants are used as antigens.

The term "blood-relationship" has been introduced by Nuttall to express certain physiologico-chemical

resemblances found to obtain among different kinds of animals. The test for determining it is found in the phenomena of specific precipitation and hemolysis.

The studies of the blood leading to present knowledge began with the work of Creite, who in 1869, found that heterologous bloods not infrequently caused hemolysis. Landois in 1875 found that the transfusion of heterologous blood into an animal not infrequently caused its death. Bordet, in 1898, found that when guinea-pigs were given frequent intraperitoneal injections of defibrinated rabbits' blood, their blood serum acquired the property of dissolving rabbits' blood corpuscles *in vitro* (hemolysis); Ehrlich and Morganroth, in 1899, showed the mechanism of such blood corpuscle solution. Tchistowich, in 1899, showed that eel's serum injected into animals produced a reaction in which the animals acquired immunity to its poisonous effects, as well as their serum the power to form a precipitate when added to the eel's serum *in vitro*. Uhlenhuth, in 1900–1901, found that the precipitation resulting from the addition of the immune serum to the antigen by whose stimulation the immune character of the serum was developed, was so specific as to be of use in forensic medicine for the certain differentiation of blood stains. Wassermann and Schutze, in 1900, prepared a serum by injecting rabbits with human blood, and tested its precipitating properties upon twenty-three different kinds of blood, finding the precipitate most marked the nearer the animal was related to man.

The work of Nuttall and his associates, "Blood-immunity and Blood-relationship," appeared in 1904, and dwells exhaustively upon the reaction of precipitation in all its phyletic relations.

Through a study of the specific precipitins we learn that though the reaction is specific—that is, takes place in greatest quantity and with greatest rapidity when the antibody is permitted to act upon its own antigen, the antigens derived from closely related ani-

mals and plants have sufficient chemical or physiological resemblance to give similar qualitative though different quantitative results.

To determine this we proceed as follows: a rabbit is given intraperitoneal injections of 5–10 c.c. of defibri-

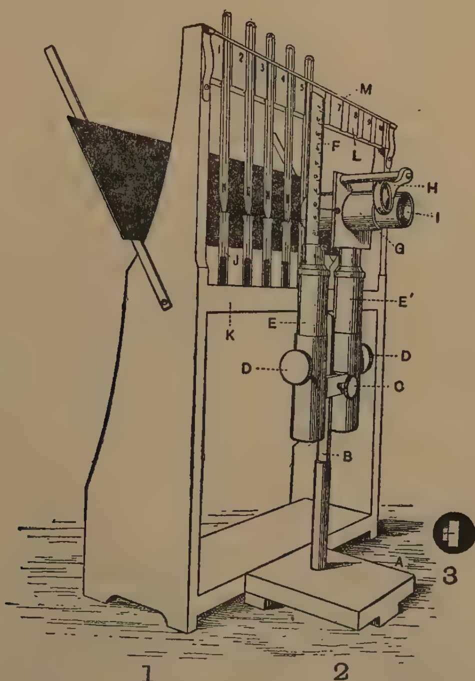


FIG. 104.—Apparatus for quantitative estimation of specific precipitation. (*Nuttall and Inchley, in "Journal of Hygiene."*)

nated human blood twice weekly for about six weeks, then bled about a week after the last injection, and the clear serum separated from the clotted blood. We thus obtain a reagent which when added to clear human blood serum immediately gives a copious white precipitate. If the antiserum be diluted 1:50 or 1:100 as a standard, so

that it shall always be present in uniform quantity in all the tests made, and the serums to be tested for blood relationship given various dilutions—1:100, 1:1000 1:10,000, 1:100,000, etc.—and the mixtures of the test antiserum and the serum to be tested allowed to stand for, say, thirty minutes as a fixed period, it will be found that the reaction of precipitation is specific in that the homologous bloods precipitate in greater dilution and in larger quantity than heterologous bloods. Thus, human serum may be precipitated with anti-human serum in dilutions even reaching 1:100,000; the blood of anthropoid apes in slightly less dilutions; those of other apes in decidedly less dilutions; those of lower monkeys in less and less dilution the further they are zoologically removed from man; those of lower mammals only in the concentrated form, if at all; and the bloods of still lower vertebrates and invertebrates not at all.

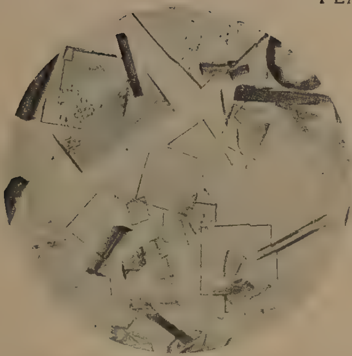
If, instead of treating the rabbit with human blood, injections of bovine blood be used and anti-bovine serum secured, the precipitation measured by the same method is found to occur in greatest intensity with ox-blood, then with the bloods of other bovidæ, then with those of animals closely related to the bovidæ, and not at all with those of animals remote from the bovidæ.

We thus have a physiologico-chemical method of confirming the morphological classification of animals. It is of interest to know that the one bears out the other in practically all cases.

The general principle may therefore be stated as follows: If the blood or body juice of one organism is capable of acting as an antigen when introduced into another organism, the two are not closely related. The index of antigenic activity is to be found in the quantitative reaction of precipitation resulting from the action of the antibody upon the homologous serum.

A most interesting and important recent addition to our knowledge of blood relationships, thought by its authors to be more accurate and discriminative than

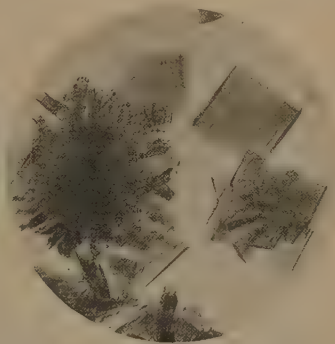
PLATE 4



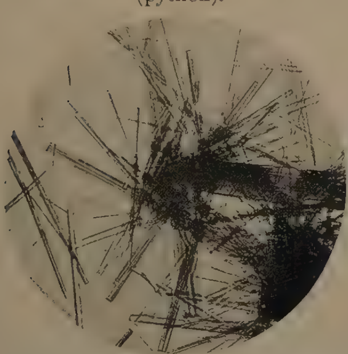
Oxyhemoglobin from a fish (carp).

Oxyhemoglobin from an amphibian (necturus).

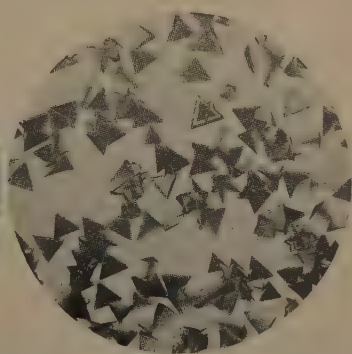
Oxyhemoglobin from a reptile (python).



Oxyhemoglobin from a bird (goose).



Oxyhemoglobin from a mammal (dog).



Oxyhemoglobin from a mammal (guinea-pig).

Plate showing the different oxyhemoglobin crystals from different classes of vertebrates. (*From photographs kindly given the author by Prof. Edward T. Reichert.*)

the zooprecipitins, is the crystallographic character of the hemoglobin of the blood. This is described in "The Differentiation and Specificity of Corresponding Proteins and Other Vital Substances in Relation to Biological Classification and Organic Evolution: The Crystallography of Hemoglobins," by Edward Tyson Reichert and Amos Peaslee Brown (published by the Carnegie Institution of Washington, 1909).

The following extracts give the deductions from an immense amount of painstaking and difficult experiment and investigation:

"The authors feel that "The trend of modern biological science seems to be irresistibly toward the explanation of all vital phenomena on a physico-chemical basis." "The striking parallelisms that have been shown to exist in the properties and reactions of colloidal and crystalloidal matter *in vitro* and in the living organism lead to the assumption that protoplasm may be looked upon as consisting of an extremely complex solution of interacting and interpendent colloids and crystalloids, and therefore that the phenomena of life are manifestations of colloidal and crystalloidal interactions of a peculiarly organized solution. We imagine this solution to consist mainly of proteins with various organic and inorganic substances. The constant presence of protein, fat, carbohydrate, and inorganic salts, together with the existence of protein-fat, protein-carbohydrate, and protein-inorganic salt combinations, justifies the belief that not only such substances, but also such combinations are absolutely essential to the existence of life."

"The very important fact that the physical, nutritive, or toxic properties of given substances may be greatly altered by a very slight change in the arrangement of the atoms or groups of molecules may be assumed to be conclusive evidence that a trifling modification in the chemical constitution of a vital substance may give rise even to a profound alteration in its physiological properties."

"This coupled with the fact that differences in centesimal composition have proved very inadequate to explain the differences in the phenomena of living matter, implies that a much greater degree of importance is to be attached to peculiarities of chemical constitution than is usually recognized."

"The possibility of an inconceivable number of constitutional differences in any given protein are instanced in the fact that the serum albumin molecule may, as has been estimated, have as many as 1,000 million stereoisomers. If we assume that serum globulin, myoalbumin, and other of the highest proteins may have a similar number, and that the simpler proteins and the fats and carbohydrates, and perhaps other complex organic substances,

may each have only a fraction of this number, it can readily be conceived how, primarily by differences in chemical constitution of vital substances and secondarily by differences in chemical composition, there might be brought about all those differences which serve to characterize genera, species, and individuals. Furthermore, since the factors which give rise to constitutional changes in one vital substance would probably operate at the same time to cause related changes in certain others, the alterations in one may logically be assumed to serve as a common index of all. In accordance with the foregoing statement it can readily be understood how environment, for instance, might so affect the individual's metabolic processes as to give rise to modifications of the constitutions of certain corresponding proteins and other vital molecules which, even though they be of too subtle a character for the chemist to detect by his present methods, may nevertheless be sufficient to cause not only physiological and morphological differentiations in the individual, but also become manifested physiologically and morphologically in the offspring."

"Furthermore, if the corresponding proteins and other complex organic structural units of the different forms of protoplasm are not identical in chemical constitution it would seem to follow, as a corollary, that the homologous organic metabolites should have specific, dependent differences. If this be so, it is obvious that such differences should constitute a pre-eminently important means of determining the structural and physiological peculiarities of protoplasm."

"To what extent this hypothesis is well-founded may be judged from this partial report of the results of our investigation: It has been conclusively shown not only that corresponding hemoglobins are not identical, but also that their peculiarities are of a positive generic specificity, and even much more sensitive in their differentiations than the "zooprecipitin test." Moreover, it has been found that one can with some certainty predict by these peculiarities, without previous knowledge of the species from which the hemoglobins were derived, whether or not interbreeding is probable or possible, and also certain characteristics of habit, etc."

"The question of interbreeding has, for instance, seemed perfectly clear in the case of *Canidæ* and *Muridæ*, and no difficulty was experienced in forecasting similarities and dissimilarities of habit in *Sciuridæ*, *Muridæ*, *Felidæ*, etc., not because it is *per se* the determining factor, but because, according to this hypothesis, it serves as an index (gross though it be, with our present very limited knowledge) of those physico-chemical properties which serve directly or indirectly to differentiate genera, species, and individuals. In other words, vital peculiarities may be resolved to a physico-chemical basis."

Though it is naturally much more difficult to determine with reference to the cells, there are reasons for believing that the cell juices, like the body juices, differ among different kinds of animals. Evidences of this

are seen, for example, in the destruction of the alien corpuscles in cases of transfusion with heterologous blood. The idea that first prompted physicians to transfuse the blood of a sheep or other lower animal into the exsanguinated human vessels was erroneous because it assumed that the red bloods were all alike. We now know that the disappointing results following such treatment depend in part upon the inappropriate character of the heterologous blood of which the patient can make little use, and which places him under the disadvantage of being compelled to dissolve and destroy all the formed elements as well as to rid himself of offensive proteids in the serum. It has been found by experience that physiological salt solution is more satisfactory in that it fills the vessels, and enables the heart to continue its work until blood regeneration begins, without introducing anything offensive into the body. Even when transfusion is practised from one individual to another of the same species—one human being to another—the result is not always so satisfactory as might be hoped, because there are individual as well as specific and racial differences, and the normal blood of one human being may in rare instances prove prejudicial to another because of the presence of preformed isolysin by which the corpuscles are destroyed, or because of the presence of offensive proteids.

When the subject of grafting is considered, it will be found that the blood relationship of the scion and the stock in both plants and animals probably has much to do with determining the success or failure of the experiment. Tissue taken from one animal and grafted upon another survives or is destroyed in large measure according to the blood relationship of the animals concerned. So sensitive are the tissues in this particular that, among animals successful grafting can rarely be performed when specific differences obtain among them.

It also appears as though this matter of blood relationship with its affinities, indifferences, or repugnances

may explain the difficulties attending successful hybridization. The germinal cells of specifically different organisms doubtless possess the same sensitivity to heterologous cells that are manifested by the somatic cells, so that, instead of fertilizing one another, they remain indifferent to one another, repel one another, or perhaps even destroy one another.

Finally, blood relationship has a distinct bearing upon the subject of symbiosis for organisms whose chemical affinities are opposed to one another may be unable to become symbionts, and in cases of parasitism, it is conceivable that one of the first adaptations to be acquired by the parasite is tolerance to the physiologico-chemically antagonistic conditons to be found in the body of the host. Indeed, as will be shown in the chapter upon Infection and Immunity, the experimental exaltation of microorganismal virulence is a matter of overcoming the body defenses, which from the present standpoint may be looked upon as the establishment of a tolerance toward originally antagonistic chemico-physiological conditions.

References.

George H. F. Nuttall: "Blood Immunity and Blood Relationship," Cambridge, 1904.

Edward Tyson Reichert and Amos Peaslee Brown: "The Differentiation and Specificity of Corresponding Proteins and Other Vital Substances in Relation to Biological Classification and Organic Evolution: The Crystallography of Hemoglobins." The Carnegie Institution, Washington, 1909.

Magnus and Friedenthal: "Ueber die Specifität der Verwandschaftsreaction der Pflanzen." Berichte der deutschen botanischen Gesellschaft, xxv, 1907, 242; xxiv, 1906, 601.

CHAPTER XIV.

PARASITISM.

A simple calculation will show that the unrestricted multiplication of any living organism would cause it to cover the entire surface of the earth in the course of a relatively short time. No organism has, however, met with such numerical success. The earth is tenanted by a highly diversified flora and fauna in which, though certain forms greatly preponderate over others in numbers, all are restricted by certain conditions that may not be overcome.

The first of these has to do with the unequal condition of the earth's surface where variations of temperature, moisture, chemical composition of the soil, exposure to violent winds and deluges of rain determine that great numbers of living things of many different kinds shall thrive in hospitable localities, diminishing numbers inhabit less hospitable localities, and none at all be found in the most inhospitable localities.

The second have to do with the behavior of the living things toward one another, which, though appearing harmonious upon cursory observation, is found upon critical examination to be an unending interference which Darwin has aptly described as the "struggle for existence."

In this perpetual strife it is easily conceived that those forms best adapted to the exigencies of the situation will survive while their less fortunate fellows must fail; hence the "struggle for existence" results in the "survival of the fittest."

These subjects are treated at considerable length elsewhere, but for an intelligent understanding of the subject

under consideration it is important to start with the idea that the "struggle for existence" is at the bottom of the parasitic association.

In a general way dissimilar living things are indifferent to one another provided they do not prey upon one another. Sometimes, however, they assume an intimacy so close that where one is found the other can always be expected. Under such circumstances it may justly be surmised that the close association is founded upon some mutual advantage that brings the two together.

To this communion of life interests the term *Symbiosis* is applied, and each of the organisms is described as a *symbiont.* In some cases the symbionts are so closely united as to appear to form a single organism, as in the lichens which consist of an alga upon which a fungus grows. This is described as *conjunctive symbiosis.* When the symbionts are less closely blended, the relationship is described as *disjunctive symbiosis.*

Symbiosis may be further subdivided into *commensalism, mutualism, helotism,* and *parasitism.*

Commensalism.—This is a form of symbiosis in which the symbionts derive no known advantage from their intimacy nor do they do one another any harm. Most interesting examples are available. One of the first to suggest itself is the little crab so commonly found in the shell of the oyster. It does the oyster no harm nor does it derive any benefit except that of the defense afforded by the strong shell of its host. When the shell is open, it is free to enter and exit at will; when it is closed, it becomes a captive. Another perhaps more interesting example is the sea anemone so commonly found upon the shell of the hermit crab. In some of these cases the anemone is attached to the claw of the crab and serves to hide the animal by closing the door of the shell when it retreats. If the crab is able to appreciate this advantage it may explain why, when the animal sheds and is obliged to seek a new home, it seizes the anemone, tears it from its old attachment,

and carries it off with it, as it is frequently said to do. In cases, however, in which the anemone is not thus situated, but is on the shell forming the crab's house, it is less easy to understand the behavior of the animal which is said at times to transfer its anemone to the new shell when its home is changed.

Commensalism among the higher plants might be exemplified by the epiphytes, plants, like orchids, that

FIG. 105.—Mutualism of diatom and bacteria. (*Verworn.*)

cling to other plants, live upon them, yet not at their expense or to their injury. In the tropics scarcely a tree can be found upon which many varieties are not present.

Mutualism.—This is a form of symbiosis in which one or both of the symbionts derives advantage from the association without injury to the other. The advantage is usually physiological in character. Thus, certain

radiolaria not infrequently harbor a small green alga, the zooxanthella. The alga gives off oxygen that is advantageous to the little animal, which in turn gives off carbon dioxide that is useful to the plant. Here both symbionts are benefited by the association.

The symbiosis of the alga and fungus constituting a lichen is a form of mutualism that may be of physiological

FIG. 106.—Tubercles, on the roots of red clover. *l*, Section of ascending branches; *b*, enlarged base of stem; *t*, root tubercles containing bacteria. (*From Bergen and Davis' "Principles of Botany." Ginn & Co., publishers.*)

benefit to both symbionts, the fungus furnishing nitrogen and the alga carbohydrates.

Again, the bacteria that form tubercles upon the rootlets of the leguminous plants are of great benefit to them by fixing nitrogen. At the same time they probably derive their nutrition from the juices of the plant without damaging it.

The bacteria that live upon the skin, in the mouth, and

in the intestines of animals are for the most part harmless mutuals that derive their nourishment from the host without causing any harm.

Certain bees live under conditions of mutualism as Psithyrus in the nests of Bombus. It is supposed that the only benefit Psithyrus receives is the shelter of the nest, but it may be that its young are nourished by the bees' honey. In return for this, Psithyrus aids in defending the nest.

Helotism.—In this form of symbiosis the one organism is supposed to enslave the other and enforce it to labor in its behalf. The term seems to be susceptible of many applications in the hands of different writers. Thus, by some it is said that among the lichens the algæ are enslaved by the symbiotic fungi. A better example is to be found in the behavior of certain ants that undertake systematic campaigns against other ants bringing home the conquered to be their slaves. The enslaved ants soon seem to be quite at home and maintain a subsequent harmonious symbiotic existence in the nests of their masters where they are easily recognized by their different specific characters. So far as known, it is only the worker ants, never the males or females, that are thus enslaved, and having no sexual instinct, but only the instinct to labor, after the heat of the action is over, they seem to be as contented to work in one place as in another. The precaution seems to be taken, however, to have them participate in the household duties rather than to engage in foraging expeditions or to join the ranks in warfare.

Parasitism.—This is a form of symbiosis in which one symbiont receives advantage to the detriment of the other. The symbiont receiving the advantage is known as the *parasite*, the other as the *host*.

The parasitic relationship is based upon the ease with which the products of another's labor can be seized upon to the saving of one's own expenditure. In most cases, therefore, the parasite is the lazy creature that lives at

another's cost. In general it is a miserable form of existence characterized by many vicissitudes and marked decadence of the parasitic forms. The actual decadence of the parasites, however, depends upon the nature of the symbiotic relationship. When this is disjunctive the parasites maintain a certain degree of independence, but when it is conjunctive they must live and die with the host.

The parasitic organisms include representatives of both cryptogams and phanerogams among plants, and of nearly all of the phyla of animals from the protozoa to the vertebrata.

According to their habits, they may be described as *occasional* or *optional parasites* and *obligatory parasites.* With the adoption of the parasitic mode of life structural modifications usually make their appearance so as to adapt the organism to its environment, after which its new mode of life becomes obligatory.

Thus, the mosquito may be cited as an example of the occasional parasite. Under conditions prevailing in many localities where mosquitoes abound, these insects live by sucking the nectar of flowers and the juices of plants. They have, however, a marked preference for the blood of animals and a few cannot ovulate except after a meal of warm blood.

The next step in the direction of obligatory parasitism is seen among organisms that visit the hosts occasionally though absolutely dependent upon them for the means of subsistence. Among such we find the biting flies, the fleas, and the bed-bugs. The latter form excellent examples, for they do not live upon the host, but inhabit crevices in the bed or cracks in the walls and sally forth at night to feed. Their mouth parts are so constructed that it is impossible for them to feed in any other way, and if the host should vacate his habitation the bugs must inevitably die, unless in the absence of human tenants they can make shift with some other warm-blooded animal that may become available. Fleas leap upon

their appropriate hosts, sometimes to satisfy their appetites, sometimes to remain. Should death overtake the particular host, they desert him for another, but should none be available, they too must die, having mouth parts solely adapted for sucking blood.

The final step is reached with the lice. One species inhabits the clothing and visits the skin to feed; other species attach themselves to the hairs and are permanent as well as obligatory parasites.

All the parasites of this class, whether they visit the surface of the body occasionally, attach themselves to it permanently, or even burrow into it, like the Sarcoptes scabei, or itch mite, are *ectoparasites*. A still more close relationship—conjunctive symbiosis—is seen in those cases in which the parasite actually enters the body of the host and inhabits its blood, tissues, or alimentary canal. Such are known as *endoparasites*.

Parasitic symbiosis not only takes place by design, but also by accident, and indeed since it may be conjectured that accident first brought about and fostered the relationship, it is difficult in some cases to say whether we are dealing with true parasitism or not. Among the infectious diseases of man and animals, and indeed of plants, we are not infrequently puzzled to know whether certain bacteria are parasites in the true sense or not. Thus, the bacillus of tetanus or lock-jaw is a rather common tenant of the alimentary apparatus of herbivorous animals with whose dejecta it finds its way to the soil in which it is sometimes found in large numbers. When this bacillus is accidentally admitted to the tissues of certain animals, it proceeds to live and multiply, and eventually, in many cases, to destroy the animal through the virulence of its toxic metabolic products. Here the accidental circumstance of a wound leads to an unexpected symbiosis that is fatal to the host and later to the parasite as well.

When this circumstance is carefully analyzed we find that one of the fundamental conditions of true parasit-

ism is wanting, for no means is provided for the future. The host dies before the bacilli have become numerous, there is little multiplication of the bacilli in the body after death, and no means is provided by which they shall leave the host to find their way to another.

FIG. 107.—The ergot of rye, *Claviceps purpurea*. Ear of rye showing two sclerotia of the fungus. 2/3 natural size. (*Partly after Tulasne.*) (*Kerner and Oliver.*)

The case is quite different with other bacteria. Thus, the bacillus of tuberculosis is unknown in nature except in the disease it causes. The microorganisms are eliminated from the body of the diseased in enormous numbers through morbid discharges and find their way to new hosts through the association of the well with the ill. Here there is little doubt of the parasitic nature of the symbiosis.

In certain cases accident may transform the symbiotic relationship from harmless to harmful. Thus the colon bacillus is to be found in nearly all vertebrates, whose alimentary tract it inhabits to feed upon the nutritious contents. When local disease of the intestine arises from any cause, invasion of the tissues by the bacilli may supervene, and the usually inoffensive organism may occasion disturbances resulting in the death of the host.

Plant parasites are innumerable and attack animals as well as other plants. Bacteria are not infrequently parasitic upon higher plants, an excellent example being found in the *wilt disease* of cucumbers and melons. The entire class of fungi is composed of organisms that must derive their nourishment from other organisms, either living or dead,

and so comprehends an enormous number of parasites. Of these, familiar examples will be the "smut" upon

Fig. 108.—Dodder, a parasitic seed plant. A, Magnified section of stem penetrated by roots of dodder; B, dodder upon a golden-rod stem; C, seedling dodder plants growing in earth; *h*, stem of host; *l*, scale-like leaves; *r*, sucking roots, or *hanstoria; s*, seedlings. (*A and C after Strasburger. From Bergen and Davis' "Principles of Botany." Ginn & Co., publishers.*)

corn and rye, the potato "rot," the grape-vine "mildew," the various "rusts," and some of the leaf curls.

Upon the roots of the Cycas, or sago palm, certain species of Anabæna are always symbiotic and perhaps parasitic.

Higher plants may also adopt the parasitic life. The "*dodders,*" so often found upon meadow plants, are typical parasites. From a seed that falls upon the ground a delicate filament makes its appearance climbing like a vine about the stems of some other plant. Soon delicate rootlets grow into the tissues of the host, and the

FIG. 109.—The European mistletoe (*Viscum album*). (*Kerner and Oliver.*)

primitive root of the parasite dies. As it now derives its entire sustenance through the rootlets that have penetrated the plant to which it clings, it can dispense with organs of its own and has neither terrestrial roots nor leaves. It grows rapidly, forming a pale colored tangled filamentous mass that bears abundant small flowers in clusters, and produces small seeds.

Other striking examples are the *mistletoes.* These plants, of which hundreds of species are known, produce

berries full of a very viscid juice which serves to glue the seeds to the branches of the trees upon which they germinate, the little rootlets striking upward and penetrating into the tissues of the host from which the parasite derives its nourishment. The stem continually forks dichotomously, each branch terminating in a pair of fleshy leaves. The flowers are small and appear at the ends of the branches and in the small divisions. As the plant is evergreen it forms a striking object in winter when it appears as a thick tangle of tiny green

Fig. 110.—Bastard toad-flax (*Thesium alpinum*). 1. Root with suckers; almost natural size; 2, piece of a root, with sucker in section. × about 35. (*Kerner and Oliver.*)

leaves and stems upon the otherwise bare branches of many common trees.

A peculiar form of vegetable parasite is the "*toad-flax*," a rather pretty flowering plant. What can be seen above ground is an independent plant with stem, leaves, and flowers of its own, but below ground its roots attach themselves to the neighboring roots of other plants which it robs and thus dwarfs.

Among animal organisms nearly every phylum has its parasitic representatives. They are most numerous among the most simple organisms and occur with dimin-

ishing frequency as the scale of life is ascended until, when the vertebrates are reached, there is but a single representative.

The following systematic arrangement of the parasitic forms is founded upon the excellent paper upon the subject in the New International Encyclopedia.

Phylum—Protozoa.

Class—Rhizopoda.—These include the amœba, of which many species are parasitic in the alimentary tracts of many other animals. The most important is the Entamœba histolytica Schaudinn, that causes tropical dysentery in man.

Class—Infusoria.—These are ciliated organisms in some cases, like Balantidium coli of man, not certainly parasitic, but perhaps merely commensals. Trichodinæ is a parasite of the gills and gill cavity of the frog; Opalina, of the bladder and gut of the frog; Holophyra, an epiparasite of certain fish; Ancistrum infests the mantle cavity of certain mollusks; Anophlophyra occurs in the intestines of certain marine invertebrates.

Class—Mastigophora.—These are flagellate organisms of which some are commensals, like Trichomonas intestinalis, Trichomonas vaginalis, Cercomonas intestinalis, and Megastoma entericum, though it is not certain that the latter is not a true parasite. They also include a number of alimentary and blood parasites, such as Herpetomonas, and true blood parasites, such as the Trypanosomes, many of which are dangerous or fatal parasites of man and the lower animals.

The Piroplasmata or Babesia and the Leishmania may also belong to this group. Many are harmful and fatal parasites of man and the lower animals.

Class—Sporozoa.—These form a large group of intracellular parasites, some, as Coccidia, being parasites of epithelial cells, others, like Plasmodium malariæ, blood parasites, and still others, like the Sarcocystis, muscle cell parasites.

Phylum—Porifera.—This seems to contain no parasitic forms.

Phylum—Cœlenterata.—This furnishes very few parasitic representatives, none of which affect man.

Class—Hydrozoa.—The Polypodium hydriforme at one stage of its life cycle is parasitic upon the immature eggs of the sturgeon. Cunina is parasitic in medusæ.

Class—Scyphozoa.—Probably has no parasitic representatives.

Class—Actinozoa.—Edwardsia is parasitic in Ctenophora; Pemmatodiscus on Rhizostoma.

Class—Ctenophora.—Gastroides is parasitic in Salpa.

Phylum—Echinodermata.—Probably has no parasitic representatives.

Phylum—Platyhelminthes.—Among these worms are many parasitic individuals infesting man and lower animals.

Class—Trematoda.—These worms are all parasitic. The best known are the liver flukes, Fasciola hepaticum and Dicrocœlium lanceolatum; the blood fluke Bilharzia hematobium and the lung fluke Paragonimus westermanii. All of these are parasites of man. In addition there are many others that infest the lower animals. Some forms require but one host, some an alternation of hosts.

Class—Cestoda.—These are the tape-worms, all of which are parasitic. Of those infesting man the best known are Tænia saginata, Tænia solium, Dibothriocephalus latus, Hymenolepis nana, Dipylidium caninum, and

Tænia echinococcus. All of these have complex life histories requiring an alternation of hosts.

Class—Turbellaria.—Of these Rhabdocœla is parasitic in the kidney of certain gasteropods; Fecampia, in the gut of certain crabs

Phylum—Nemathelminthes.

Class—Nemertinea.—Of these worms few are parasitic. Malacobdella, however, is parasitic in Lamellibranchs.

Class—Nematoda.—These are the round worms, of which some species live independent lives, though perhaps the greater number are parasitic. A few infest plants, most of them animals. Their distribution is so broad that few of the higher animals escape them, and they extend from the arthropoda through the whole series to man himself. Of the human parasites of this class the Ascaris lumbricoides or round worm, the Oxyuris vermicularis or pin-worm, the Anchylostoma duodenale or the palisade worm, the Necator americana or hook-worm, and the Trichocephalus dispar or whip-worm are intestinal parasites. Trichinella spiralis is at one stage an intestinal parasite, but later a muscle parasite. Filaria bancrofti is a blood parasite and Filaria medinensis, a tissue parasite. All are of rather frequent occurrence. It is not in all cases possible to separate commensalism and mutualism from parasitism in discussing these worms.

Class—Acanthocephala.—This contains four genera and a number of species, all of which are parasitic. They infest arthropods for the most part during the immature stage, the adults appearing in vertebrates, especially fishes where they frequent the intestine. They are rarely found in man.

Phylum—Trochelminthes.—These comprise the rotifers or wheel animalcules, and are rarely parasitic.

Class—Rotifera.—Of these a few species are parasitic in crustacea.

Phylum—Annulata.—Of the segmented worms few are parasitic.

Class—Archi-annelida.—These embrace a number of parasitic forms, none of which infests man.

Class—Discophora.—These embrace the leeches which may be included among the occasional or optional parasites. They live by attaching themselves to fishes and sometimes to warm blooded animals, sucking blood until distended, then letting go again. They are parasitic in the same manner as bed-bugs and fleas.

Phylum—Mollusca.—Of the mollusks very few are parasitic.

Class—Gasteropoda.—Of these Eulima, Stylifer, and Thyca are parasitic in Holothurians, star-fishes, and Echinoids, embedding themselves in the skin where their presence occasions growths resembling tumors.

Phylum—Arthropoda.—This is a phylum rich in parasitic forms of great interest.

Class—Crustacea:

Entomostraca.—These include the water fleas or Copepods of which many are parasitic. Argulus is an epiparasite of fishes, boring between their scales; Caligus is parasitic upon the gills of fishes; Leraconema an endoparasite of the muscle of fishes. These parasites are very harmful to their respective hosts.

Another group, of which the barnacles, the Cirripedia, are well-known members, furnish a few parasitic forms that attach themselves to the abdomens of crabs.

Arthrostraca.—Of these the Amphipoda present a few forms—Cyamus—that are parasites of whales, and of the Isopoda, many forms that are parasitic upon the gills or scales of fishes.

Class—Hexapoda—Insects.—Of parasitic insects there seems to be no end, nearly every order appearing to be represented in some form of injurious symbiosis with other insects or upon other animals or plants.

Order—Mallophoga.—All of the insects of this order are parasitic upon birds and mammals, the symbiosis being conjunctive. They in general resemble lice, are without wings, have biting mouth-parts, not fitted for sucking blood, and live by eating the feathers and hairs. Five species belonging to three genera are known to infest the barnyard fowl. Other species infest other birds. Certain species sometimes, but rarely, infest the dog and cat.

Order—Hemiptera.—This order includes the "bugs" and true lice, the plant lice and the scale insects. The mouth-parts of the entire group are fitted for piercing and sucking. Most of them live by sucking vegetable juices; some are predatory and seize upon other insects, sucking their blood; some, like the lice and bed-bugs, suck the blood of warm-blooded animals. The scale insects, red-bugs, and plant lice do great damage to crops.

Order—Lepidoptera.—This order which comprises the butterflies and moths includes a great number of representatives that are parasitic upon plants in the larval state. One is a parasite of bees' nests, devouring the wax and so ruining the combs. The family Epiphyropidæ have larvæ that live upon the backs of

leaf-hoppers (Homoptera), eating the sugary and waxy secretions discharged by the hosts.

Order—Diptera.—This large order, the flies, contains many representatives of strikingly different appearance, whose mouth-parts are fitted for sucking the juice of plants or the blood of animals, either in the pupa or imago stages. It also contains quite a number whose habits

FIG. 111.—Botfly in stomach of horse, also adult fly. (*After Michener, Report on Diseases of the Horse, U. S. Department of Agriculture, Bureau of Animal Industry.*)

of ovulation are parasitic. A few forms are obligatory external symbionts, as Melophagus ovinus, the sheep tick.

The flesh flies not infrequently lay their eggs upon wounds and in discharging openings of the bodies of animals where the maggots work their way into the tissues. Though most cases of myiasis seem to be by accident rather

than by design, the "screw-worm" appears to prefer animal tissues to other available food for its young.

The botfly fastens its eggs to the hairs of horses, from which position they are licked off and swallowed, to hatch in the animal's stomach. The larvæ attach themselves to the mucous membrane, where they remain until ready to pupate, when they let go, pass through the pylorus, and reach the anus by the time the imago is ready to emerge.

The sheep bot lays her eggs at the nostrils of the sheep, from which the hatched larvæ ascend to the frontal sinuses where their presence causes vertigo and sometimes the death of the sheep. When the larvæ are mature they escape from the nose and pupate on the ground.

Botflies of the genus Hypoderma sometimes form tumors through irritation of the skin in which the larvæ develop. The "ox-warble," like the horse bot, lays its eggs on the skin, from which they are licked and swallowed. The larvæ make their way through the œsophagus, to the subcutaneous tissue, where they cause tumor-like swellings from which they bore out at maturity, leaving permanent holes in the animal's hide.

Many biting flies, Stomoxys, Glossina, etc., not only annoy warm-blooded animals by biting them, but act as hosts of parasites which they take from the blood of one animal, and pass to healthy animals subsequently bitten. The discovery that the trypanosomes of "tsetse fly disease" of animals and "sleeping sickness" of man are spread by the Glossina morsitans and Glossina palpalis, respectively, and that those of "surra" and *mal de caderas* are similarly spread by Stomoxys is of marked economic

PLATE 5

Holcaspis globulus. A, Galls on oak, natural size; B, the gall-maker, twice natural length (*Folsom*).

A tomato worm, *Phlegethontius sexta*, bearing cocoons of the parasitic *Apanteles congregatus.* Natural size (*Folsom*).

importance, since means of inhibiting the multiplication or development of the flies will go far in lessening the incidence of these destructive maladies.

In the same manner mosquitoes have been shown not only to be optional parasites themselves, but also to act as definitive hosts of other parasites that they transmit from individual to individual. Such parasitic diseases of man as paludism or malaria, yellow-fever, and filariasis are thus transmitted and suspicions are abroad that other diseases may be similarly spread.

It was only through intelligent understanding of the relation of the mosquito to yellow fever that permitted the eradication of the disease from Havana and Panama.

Dipterous insects are also important plant parasites sometimes penetrating the tissues in the larval state to complete their metamorphosis, sometimes stinging the plant during ovulation and causing the formation of galls or tumors upon the tissues of which the larvæ live.

Order—Siphonaptera.—This order includes the fleas, of which there are many species peculiar to different animals, though occasionally in case of necessity feeding promiscuously upon warm-blooded creatures. The symbiotic relationship varies in closeness in different cases. Upon hairy animals the fleas remain in more intimate association than upon man. The fleas have a disposition to leave the host occasionally and hop about the ground, perhaps to find new hosts. The parasitic life only appertains to the adult stage, the larval and pupal stages occurring upon the ground where vegetable food is consumed. One flea, the Sarcopsylla penetrans, is peculiar in that the female

buries herself beneath the skin of the host, the abdomen then swelling to great size and causing itching papules or "chiggerbuttons" to form upon the skin.

Order—Coleoptera.—Of these insects, the beetles, a vast number are parasitic, in some or all of their stages, upon plants, every imaginable structure being attacked by some kind of beetle.

Beetles are, however, very rarely parasites of higher animals and rarely parasites of other insects. An exception to this is found in the interesting Stylopidæ, which live between the abdominal plates of certain hymenopterous insects, the abdomen out of sight, the head peeping out; another is found in Peatypsyllus castris, which is an external parasite of the beaver.

Order—Hymenoptera.—This great order of insects furnishes the greatest numbers and most interesting examples of parasitism. In the family Ichneumonidæ more than ten thousand parasitic species are already known, with accessions constantly being made.

Some of the hymenoptera are plant parasites and, like the dipterous insects of similar habits, sting the plants at the time of oviposition in such manner as to form galls and other excrescences, upon the tissue of which the larvæ feed. The usual habit of the hymenopterous parasites is to ovulate in the larvæ and pupæ of other insects, the eggs hatching in their bodies and the larvæ feeding upon the blood and fat until ready to pupate themselves, when they usually bore their way out and spin silken cocoons, in which they mature. A familiar example of such a hymenopterous parasite is found in Apanteles congregatus, which tiny insect lays

its eggs in the tomato worm and other Sphingidæ; the little cocoons which the caterpillar carries fastened to its back giving its body the appearance of being covered with rice grains.

Many species are provided with remarkably long ovipositors with which to reach the larvæ, which may lie hidden away under bark, in burrows in wood, in tunnels in the earth, or with which they bore through cocoons to reach the insect hosts at the beginning of the stage of pupation.

Some of these insects (Megarhyssa lunator and Pimpla) are large and robust, measuring 8 to 10 cm., and provided with ovipositors, 20 cm. or more in length; others, the Proctotrypidæ, are so tiny as to be enumerated among the smallest known insects. Such minute insects oviposit in the eggs of other insects and of spiders.

The hymenopterous parasites are of immense benefit to man by holding in check his chief insect enemies, especially coleopterous and lepidopterous insects. For the destruction of the cotton worm and the Hessian fly, we are entirely under obligations to them.

It is interesting to observe in conclusion that the parasitic habit is so largely developed among the hymenoptera that super-parasites—*i.e.*, parasites of parasites—may reach even the third and fourth degree.

Class—Arachnida.—Of this class which includes the ticks and mites, the scorpions and spiders, we find practically all of the ticks and one-half of the mites to be parasitic, either upon animals or upon plants.

The ticks comprise two families, the Argasidæ and the Ixodidæ which form the superfamily

Ixodiodea. The eggs usually hatch upon the ground yielding six-legged "nymphs" or larval forms. With the second moult they acquire a fourth pair of legs and become mature. The young ticks climb the stems of plants and there await the coming of some warm-blooded animal to which they quickly transfer themselves. The proboscides of the little ticks cannot reach

Fig. 112.—Pyroplasma bigeminum. Cause of Texas fever in cattle, in stained blood of steer. × 1000. *a*, **Leucocyte;** *b*, **normal erythrocyte;** *c*, **erythrocyte containing one pair,** *d*, **erythrocyte containing two pairs of pyroplasmata.**

the blood, but their introduction into the skin sets up an inflammatory reaction with some edema and the lymph nourishes them. The bites sometimes suppurate. When full-grown the proboscis easily penetrates the skin, and the parasites slowly distend themselves with blood to a surprising extent. The male tick does not seem to be much of a blood sucker, bites occasionally, and is satisfied with little; the

female, however, inserts its proboscis into the skin once for all and attaches itself so firmly that it cannot be pulled loose without tearing away its mouth parts. It does not let go until it is completely filled and has been fertilized by the male when it drops off to lie helpless on the ground, where after a short time it discharges a large mass of round transparent eggs from which the embryo ticks hatch.

Where ticks are numerous they may be troublesome. They may attach themselves without

FIG. 113.—Ornithodorus moubata. Tick that transmits African relapsing fever: *a*, Viewed from above; *b*, viewed from below. (*Robert Koch.*)

any sensation or disturbance of the host, or their bites may cause intolerable irritation. Their chief importance depends upon the fact that they harbor certain parasites which they transmit from animal to animal, not always directly, since they rarely visit more than one host, but by taking the parasites from the animal frequented, and passing them through the eggs to a new generation through which new animals become infected. It is in this manner that the "Texas fever" of cattle, a

very dangerous and destructive malady is transmitted. African relapsing fever is transmitted to man by the African tick, Ornithodorus moubata, and in the Rocky Mountains a febrile affection, known as bitter root fever, has also been traced to the bites of ticks. The spirillosis of fowls and ducks is spread by the ticks (large lice) that infest them. Of the *Mites* large numbers frequent plants,

Fig. 114.—Spirochæta duttoni. Rat blood. × 1500. (*After Novy.*)

sucking the juices and causing the leaves to dry and curl. Grain mites, that normally frequent and undoubtedly live upon the stems and hulls of grains seem quite ready to infest man when opportunity offers. Thus an extremely minute mite of this kind, Pediculoides ventricosus, much too small to be seen without the aid of a lens, and commonly found upon straw, sometimes renders miserable the lives of those that

sleep upon straw beds by being shaken through the ticking, penetrating the clothing, and working their way into the skin and causing severe dermatitis. The female mite introduces its proboscis into the skin, and distends its body to an enormous extent while the surrounding tissues swell until an umbilicated vesicle or pustule, not unlike that of small-pox, is formed. A more familiar mite is the Acarus scabei, that which causes the "itch" or *scabies*. The female bores tunnels in the epidermis, causing hyperemia, vesication, and pustulation associated

FIG. 115.—Pediculoides ventricosus (enlarged). (*After Laboulbène and Mégrim.*) *a*, Male; *b*, young; *c*, mature female.

with great itching. Scabies is by no means confined to man, but appears in sheep as "sheep-scab," and in dogs, cats, horses, and cattle as the "mange."

A familiar but no less disagreeable mite is the "blackberry tick" or "harvest bug," the Leptus autumnalis, which, frequenting long grass and blackberry bushes, not infrequently finds its way to the human skin into which it thrusts an enormously long proboscis. Its irritating saliva causes considerable irritation, weal formation, and intense itching. When these mites are

numerous the victim suffers considerable malaise and some elevation of the body temperature. As the weals form, the bodies of the mites become surrounded by the tumefied skin and appear as minute transparent red points at the centres of the weals. The life-history of these mites is not completely known.

The ticks and mites are not all parasitic upon

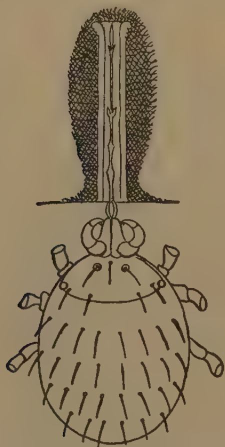


Fig. 116.—Leptus autumnalis. (*After Trouessart.*)

warm-blooded animals; a few infest snakes, reptiles, and even fishes.

A peculiar arachnid, probably related to the mites, the Liguatulid, is parasitic upon the tongue of dogs.

Phylum—Chordata.—Of the vertebrates there are very few parasitic representatives.

Class—Pisces.—The Hag-fishes may with propriety be classed among the parasites. The common hag, Myxine glutinosa, is an eel-like fish, not infrequently 18 inches in length.

It has a cartilaginous skeleton, eyes deeply embedded in the skin, and a mouth so rudimentary that it consists of a mere membranous ring furnished with a single tooth in its upper part. The tongue, however, is furnished with two rows of strong teeth. Around the mouth are eight short tentacles. With the tongue as a piston and using the mouth as a sucker, the hag attaches itself to a halibut or other large fish, holds on firmly and gradually bores its way into the body cavity, consuming the flesh of the fish until only the skin, entrails, and cartilaginous skeleton remain.

It is indispensable to successful parasitic existence that the symbiotic relationship be so adjusted that means are provided for the escape of the parasites or their offspring in order that new generations in new hosts may obtain. With the ecto-parasites this is a simple matter, but with those living within the bodies of the hosts it is more difficult.

The means of transmission is very varied and in many cases very interesting. With the ocasional parasites, such as the mosquitoes, fleas, bed-bugs, and some of the ticks, the symbiotic union is so indefinite that the host is not fixed. With the lice which actually live upon the host, the transmission of the adult parasites is the accidental result of the intimate personal association of the hosts. In case of such emergency arising as the death of the host, the parasites being unable to seek new hosts, remain upon, and die with, or rather after him.

The intestinal worms discharge enormous numbers of eggs which pass out with the excrement, admission to fresh hosts being a matter of chance. In such cases it is usually at the sacrifice of countless eggs and embryos that one is preserved by entrance into a new host. Thus the eggs falling upon the soil must wait in some cases until an appropriate animal, browsing upon the herbage,

takes them up with the rootlets of the plants. In such cases it may be that the animal from which the ova come or one of its fellows that can act as host, or it may be an entirely different kind of animal by which the egg must be swallowed, in order that development may occur. The intestinal parasites of man furnish interesting examples of direct and indirect infection. The pin-worm or seat-worm (Oxyuris vermicularis) so common in children, occasions considerable local irritation about the anus and causes the host to scratch the part, thus taking up the eggs with the nails and carrying them later on to the mouth, directly infecting himself and continually adding to the number of his parasites.

The round worm, Ascaris lumbricoides, discharges eggs surrounded with a thick albuminous coating that enables them to resist drying for a long time. Such eggs find their way to foods in water, in dust, or by being carried by flies, or adhering to vegetables fertilized by human excrement, may be swallowed and reach the stomach where the albuminous capsule is dissolved by the digestive juices and the embryo set free to mature in the intestine. The hook worms, Anchylostoma duodenale and Necator americana, produce abundant eggs which, after having been discharged in the excrement, develop in moist soil into diminutive embryos which attach themselves to the skin of the feet or hands, bore through, enter the capillaries, and are carried by the blood to the intestine where they develop into the adult parasites. The eggs of Schistosoma hematobium, falling into water, develop into a ciliated *merecidium* or embryo. Whether this reaches new hosts by directly perforating the skin during bathing or must be swallowed is not yet known.

In all of the examples thus far given the transmission of the parasite is said to be direct; that is, from host to host of the same kind, the independent embryonal life being quite short.

But in many cases the embryonal life of the parasite

is so long that a new cycle in a second host is required to bring the parasite to maturity. Such conditions attend the lives of the tape-worms. The eggs of these parasites leave the body of the host with his excrement and presumably scatter upon the soil. It has been found by experiment that should any of these eggs be swallowed by the same host or a host similar to that in whose body they were produced, they sometimes at once

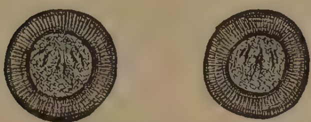


FIG. 117.—Eggs of Tænia Saginata.

FIG. 119.—Head of Tænia saginata. (*Mosler and Peiper.*)

FIG. 118.—Mature segments of Tænia saginata.

develop into the adult organism, but this is by no means the rule and the chances seem to be in favor of their being swallowed by some other animal in whose body they develop differently. Thus taking as an example the most common tape-worm of man, Tænia saginata, the beef-worm, it is found that its eggs, presumably taken from the soil by grazing cattle, develop in them to an embryo in no way similar either in appearance or

habit to its parent. Instead of growing into a long segmented worm, the egg develops into a short embryo which undergoes a peculiar cystic expansion of the first segment into which the head and neck are withdrawn, forming a distinct parasitic cyst or *scolex*. Such embryos do not inhabit the intestine, but in some way leave that viscus to encyst themselves in the muscles of the animal, take up a kind of inactive existence, and await the chance of being eaten by man with the flesh of the ox. Should flesh containing such an embryo or scolex be eaten raw—the embryo is, of course, killed by cooking—it emerges, as it experiences the stimulating

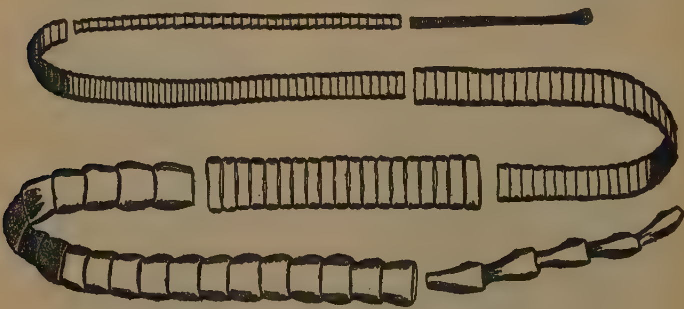


FIG. 120.—Tænia saginata. (*Eichhorst.*)

action of the digestive juices, thrusts out its head, attaches itself to the intestinal wall by its cephalic suckers, and develops into an adult worm or *strobila*. We thus find that for parasites of this class there are two separate cycles of life, lived in two different hosts in alternation.

Of the human parasites the intermediate hosts are numerous and varied; thus for Tænia saginata it is the bovine species; of Tænia solium, the hog; of Dibothriocephalus latus, the pike; of Paragonimus westermanii, a mollusk.

Man is himself the intermediate host of Tænia echinococcus, the adult of which infests the dog.

Blood parasites, shut in the circulatory apparatus,

were for a long time a source of much perplexity as no means for transmission from animal to animal could be found. It was agreed on all sides that the malarial parasites did not leave the body in the expired air, in the urine, or in the feces; the embryos of Filaria bancrofti (Filaria sanguinis hominis) were in the blood in large numbers, but could not be traced from the body, their occasional appearance in the urine being undoubtedly accidental. It was the genius of Manson that afforded the first clue. Finding that the embryos of Filaria bancrofti appeared in the blood at night, he conjectured that it might be to adapt them to the visits

FIG. 121.—Filaria embryo, alive in the blood. (*F. P. Henry.*)

of some nocturnal blood-sucking insect. Working upon this hypothesis, he and Low found that when a common mosquito, Culex pipiens, draws blood containing these worms into its stomach, the embryos shed their hyaline sheaths, bore through the intestinal wall, migrate to the thoracic muscles, and encyst themselves at the base of the proboscis. After a period of rest, the worms, feeling the stimulating effects of warm blood as the mosquito bites again, leave the muscles, enter the proboscis, and work their way into the tissue of the newly bitten host.

The further history is uncertain; presumably the embryos at once take up their habitat in the lymphatic

system, grow to maturity, and later fill the blood with their own embryo-descendants.

This discovery led Manson to suspect that the malarial parasite might have a similar intermediate, and experiments with mosquitoes showed him that when blood containing malarial parasites was taken into the mosquito's stomach-intestine, the parasites underwent a change known as flagellation, which was suspected to be the beginning of a new life cycle. Manson was not able to perfect this work, but his pupil, Ross, acting upon his suggestions, worked patiently upon the problem in India and succeeded in showing that certain mosquitoes, the genus Anopheles, do act as hosts of the parasites.

Fig. 122.—Filarial worm (*a*) in proboscis of Culex pipiens.

The last step in a complete understanding of the life history of the parasites was made by MacCallum in this country.

In brief, the life history is as follows: The parasites live one cycle in the body of man, where they first appear as minute amœboid bodies in the red blood corpuscles. These grow and destroy the corpuscles until they attain to an almost equal size, when they divide into a varying number of small bodies or spores (the parasite belongs to the class Sporozoa of the Phylum Protozoa). These spores at once attach themselves to other corpuscles and repeat the phenomena of growth and sporulation and so on, a new crop maturing every third or fourth day

according to the species of the parasite. When the number of parasites in the blood becomes considerable, a variation presents itself in that some of adult parasites that do not sporulate, but remain large, ovoid or crescentic bodies, the gametes, or sexually perfect parasites. When the blood is drawn, either for microscopic examination in the fresh state, or by the mosquito, a change takes place in certain of these bodies which become actively amœboid, show tumultuous cytoplasmic stream-

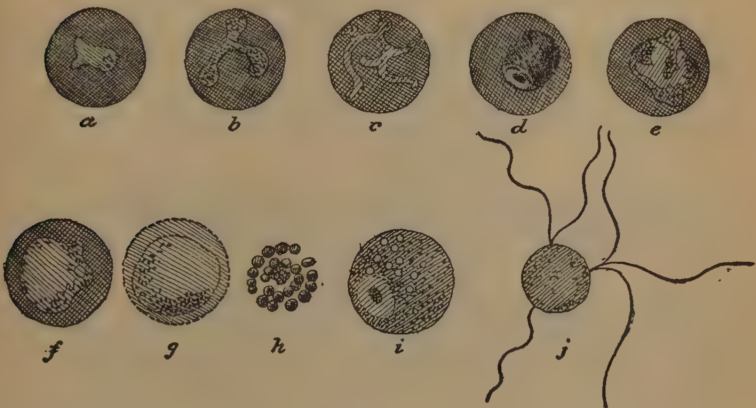


FIG. 123.—Parasite of tertian malarial fever. *a*, *b*, *c*, *d*, *e*, *f*, *g*, Growing pigmented parasite in the red blood corpuscles; *h*, spores formed by segmentation of the parasite—no roset is found, but concentric rings of the cytoplasm divide: *i*, macrogametocyte; *j*, microgametocyte with flagella.

ing, and then emit delicate filamentous bodies of minute size formerly called "flagella." It was supposed by Manson that these were the essential parasitic forms of the mosquito cycle, but MacCallum showed that they are the spermatozoids of the parasite, and he was able to follow them to the female gametocytes or oocytes and actually observed the process of fertilization in the case of an avian malarial parasite known as Halteridium danelewskyi.

When fertilization has taken place in the mosquito's

body, a vermicular zygote results, which penetrates the intestinal wall and remains attached to its outer surface, projecting into the abdominal cavity. The zygote enlarges, breaks up into numerous zygomeres, each

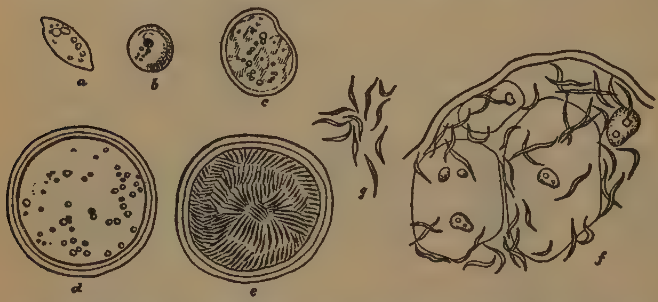


FIG. 124.—Developmental cycle of the malarial parasite in the mosquito. *a*, *b*, *c*, Zygocytes; *d*, *e*, meres with contained blasts; *f*, blasts migrating into the salivary gland-cells. (*From Manson.*)

of which eventually divides into a large number of sporozoits of falciform shape which migrate to the cells of the salivary glands, from which they enter the insect's saliva. This transformation requires from ten

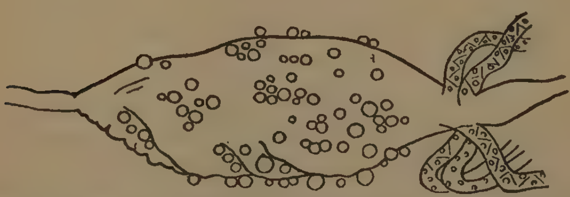


FIG. 125.—Stomach of mosquito with zygocytes on the outer surface.

to fourteen days, according to the temperature. When the mosquito subsequently bites, the sporozoits entering the blood of the new individual attach themselves to the red corpuscles, and again begin the human cycle.

Thus, in each of these cases the parasite lives alternately in two hosts, one of which, the insect, acts as the distributor.

These discoveries gave a great impetus to the investigation of the means by which the blood parasites were transmitted, and it is now known that the trypanosomes of rats are transmitted by their insect parasites, the trypanosomes of Nagana by the "tsetse fly," Glossina morsitans, and the trypanosome of African lethargy by

FIG. 126.—Glossina palpalis (× 3 3/4), the carrier of the trypanosome of sleeping sickness. (*After Adami.*)

another tsetse fly, Glossina palpalis. It has also been discovered that the trypanosomes of Surra and of mal de caderas are transmitted by a biting fly fairly well identified as Stomoxys calcitrans; and that the spirochæte of African relapsing fever is transmitted by a tick, the Ornithodorus moubata.

The mention of the tick introduces another matter of interest, for it is not the tick that sucks the blood that transmits the disease, but its progeny which have been infected as eggs in the body of the mother.

The spirochætes have actually been seen in the mother's body in the ovaries and in the eggs themselves.

These observations make clear the transmission of Texas fever by the Ripicephalus bovis. The female tick distended with the infectious blood drops off, oviposits, and dies, but the immature ticks transmit the disease to cattle so soon as they reach them. The explanation is found in the passage of the parasites into the egg and the infection of the embryo, though this has not yet been seen.

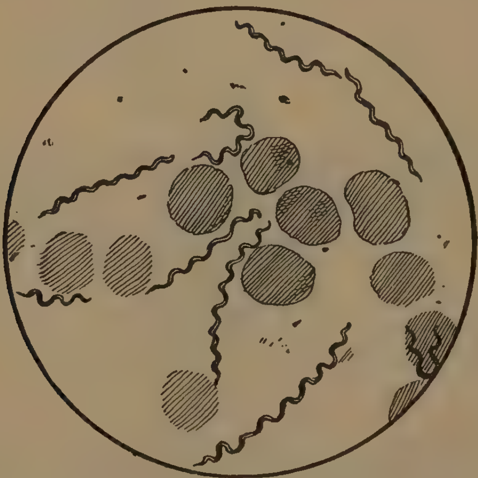


FIG. 127.—Spirochæte obermeieri. (*Novy.*) Rat blood. × 1500.

Even in cases in which the specific parasite has eluded discovery the application of these parasitological principles has borne fruit. Thus no microparasite has yet been discovered for yellow fever, yet it has been determined that whatever it is, it is harbored and transmitted by the mosquito Stegomyia calopus, and that it undergoes some change in the body of that insect, the perfection of which requires about twelve days.

In considering the reciprocal relations of the parasites

and their hosts it is important to remember that the host is necessary to the parasite and that his untimely death may interrupt one of the developmental cycles by which the permanence of the parasite is secured. The continuance of the parasitic relationship may therefore be referred to the circumstance that the danger to the host is not so great as to prevent the completion of at least one generation of the parasites, and the preparation of one crop of eggs or embryos for future activity. The waste in parasite eggs and embryos is immense; enormous numbers are produced, few survive.

The assumption of parasitic existence also entails structural decadence on the part of the parasites. Organs of locomotion become less and less useful; organs of special sense superfluous, and, taking the tape-worms as examples of the extreme degree to which such decadence may arrive, we find these animals without organs of locomotion, without organs of alimentation, without organs of special sense, without organs of circulation, without organs of respiration, and consisting of a minute head, a short neck, and a long series of *proglottides* or segments, each of which is a kind of independent bisexual reproductive animal, virtually an independent entity in itself. The entire energy of the organism is thus concentrated upon the reproductive function that progeny may be insured.

References.

R. Leuckart: "Die Parasiten des Menschen," etc., Leipzig, 1881.

M. Braun: "Tierische Parasiten des Menschen," Würzburg, 1908.

The New International Encyclopedia: Article upon "Parasites."

Joseph McFarland: "Text-book on Pathology," Phila., 1910, Chapter upon Parasitism.

CHAPTER XV.

INFECTION AND IMMUNITY.

When parasitic symbionts are fairly large they are said to *infest* the host; when very small, to *infect* him. Between infestation and infection no sharp distinction can be drawn, though it is probably more correct usage to employ the term "infection" for the invasion of the body by microparasites of *any* kind. Any object upon which such organisms may be brought into the body is said to be *infective.* The body into which they are brought is said to be *infected,* the organisms through which the infection is brought about are said to be *infections.* Infection, being a form of parasitism, implies injury of the host by the microparasites.

Infecting organisms are, therefore, always *pathogenic,* or capable of exciting anatomical or physiological disturbances. The injurious quality of the organism is characterized as its *virulence,* and depends upon conditions attending its metabolism. Thus, it may liberate enzymes, it may produce toxic proteids, it may transform the chemical reaction of the surrounding media, or it may facilitate its own invasive powers by giving off certain offensive substances (*aggressins*) by which the defensive reactions of the host are inhibited in action.

The almost universal prevalence of bacteria determines that no higher organism escapes contact with them. Through how wide a range their power of invading the tissues of other living things may extend is difficult to answer; it is doubtless very wide, and includes both plants and animals.

Certain microorganisms are invariable commensals of the higher organisms, frequenting various portions of the body upon which or in which the conditions of life are favorable to them. When accident determines that such shall be carried into the tissues, they may or may not be able to survive the change. In most cases they quickly succumb to the unusual conditions. In other cases they survive for a limited time, during which the host suffers more or less disturbance, and after which their vitality wanes, they die out and the damage they have effected may be repaired. Far more injurious are the new and strange microparasites with which one occasionally comes into contact. Some of these are actively invasive, find their way from the skin, the respiratory or the alimentary organs into the blood, distribute throughout the body, sometimes exciting local histological changes in the tissues, sometimes general physiological disturbances, as fever, etc. Such organisms may quickly or slowly destroy the host, though in perhaps a majority of the cases they, too, become less vigorous as time goes on, and die out, leaving the patient to recover if not too much damaged by their inroads.

All grades of invasiveness occur. Some microparasites find a very superficial and restricted field of operation; some penetrate more deeply and are carried in small numbers in the lymph and blood vessels to the viscera where they slowly occasion minute changes, and still others freely distribute through the blood and affect the entire constitution of the host.

The products of the microparasites must not be neglected when considering their pathogenesis; they pass through all grades of harmfulness. Some microorganisms, though they invade easily, produce only a mild fever; others incapable of extensively invading the body of the host, form poisonous products which when absorbed into the blood affect tissues remote from the seat of microparasitic invasion. This is well exemplified by

the bacillus of tetanus which, though unable to invade the body generally, eliminates a soluble toxin that usually causes the death of the host by its exciting action upon the nervous system.

In order that infection be possible, certain conditions must be fulfilled. These, which may be described as the *cardinal conditions of infection* are: 1. The infecting organism must enter the host in sufficient number; 2. It must enter by an appropriate avenue; 3. It must be virulent; 4. The host must be receptive.

Among such delicately organized bodies as the micro-parasites the tenure of life is short, and any radical change is apt to be accompanied by a high mortality. When we endeavor to determine the actual number of micro-organisms, in any culture, requisite to infect, we usually find that not a few of the counted and estimated organisms are already dead. Infectivity is, moreover, a quality not possessed by all the organisms in equal degree. Some are more infective than others, so that it is usually necessary for a considerable number to enter the host in order that sufficiently virulent organisms may survive the change and effect the invasion.

The number of organisms naturally bears some relation to their *virulence* or injurious power. If they are of slight virulence a much greater number may be required than when they are highly virulent. Virulence is a variable quality, comparable to the color or perfume of flowers, and, like them, subject to modification through circumstance. It is not known whether mild virulence signifies that all of the organisms in a culture are uniformly weak in this particular or that many or most of them are. Presumably it is the latter, for when the culture is experimentally placed under conditions favorable to virulence, it sometimes speedily revives. Thus, if bacteria are transplanted many times upon artificial culture media they lose, but if they are passed through a succession of animals for which they are invasive, they increase in virulence. This makes it

appear as though among the individual bacteria comprising the culture some were pathogenic and some vegetative. When the organisms are frequently transplanted from culture medium to culture medium, the vegetative individuals thrive best and eventually alone survive, the others having been outgrown and outlived, after which no virulence can be revived. When, on the other hand, they are frequently passed through animals the pathogenic individuals thrive and the vegetative ones are eliminated.

The *avenue by which the microparasites enter the host* seems to be of importance. Certain species thrive only when taken into the alimentary organs; others only when applied to the mucous membranes; still others only when taken into the respiratory organs. The avenue of entrance also determines the form that an infection may take. Thus streptococci, minute spherical organisms, hanging together like a string of beads, may cause erysipelas if entering through the skin; sore throat with the formation of a false membrane if taken into the mouth; abscesses if carried into the deeper tissues; puerperal fever if introduced into the uterus, and disease of the valves of the heart if into the circulation.

The host must be in a receptive condition. This is one of the most interesting of all the cardinal conditions, implying as it does some variation in the physiologico-chemical condition of the host by which the invasive power of the microparasites is made possible or impossible. When the host is receptive it is described as *susceptible;* when resistant, as *immune.*

Immunity may be defined as a physiologico-chemical condition of the host by which its invasion by microparasites is made impossible. When one inquires the nature of this physiologico-chemical condition by which the invasion by micro-parasites is made impossible, he enters upon an investigation the scope and complexity of which seem to increase as the subject is pursued. Microparasites eliminate "aggressins" tending to de-

stroy the body defenses, toxins by which the cells of the host are poisoned, enzymes by which they are dissolved, and alter the chemical reaction of the tissues in which they arrive. Before the parasite destroying mechanism can be set in operation, therefore, something in the way of endurance, tolerance, or immunity against the microparasitic products becomes essential. The reactions of immunity, therefore, become exceedingly complex. They embrace two essentials—*ability to endure the microorganismal products without injury* and *ability to destroy the microparasites.*

Before further pursuing the subject of infection, a brief space must be devoted to general considerations that bear upon the subject of immunity.

Habit has much to do with the general vital processes. It is exemplified by the change of animals from the independent and synthetic to the dependent and analytic mode of nutrition; by the remarkable differences in the behavior of aquatic animals to salt and fresh water. The great marine mammals, the fishes, the numerous phyla of marine invertebrates, and large numbers of marine birds find sea-water with its heavy percentage of sodium chloride and other salts unobjectionable; other animals and plants habituated to fresh water are poisoned by it; still other animals and plants living in the mouths of rivers endure alternating immersion in salt and fresh water resulting from tides and currents without injury. The precisely arranged adaptations under which living things present themselves to observation at the present time are the result of divergences begun long ago, and fail to suggest the tremendous sacrifice of life though which they have probably been adjusted.

Every creature is found upon examination not only to consume by preference some particular kind of food, but to find radical departure from it fatal and even slight departures harmful. Even where the diet appears to be of mixed nature it is limited to a few, not to all

available foods. Should one inquire how and why this began, the question leads inevitably into the consideration of the greater problems of evolution, for it is clear that such conditions cannot always have obtained, seeing that there must have been a time when neither the living thing nor its food was in existence. That which is consumed must have come into existence before that which consumes it. It can be shown that the food habit of existing animals sometimes undergoes considerable modification. Thus the Colorado potato beetle, in its native habitat, Colorado, fed upon certain plants of the genus Solanum. These plants were not very common, and the beetles were not very numerous until civilization arrived and they, by preference, seized upon the potato, a related plant, and have become a great nuisance to the farmer. Perhaps it is not unusual for animals to try a new means of subsistence; if so, we can only know about it when they are successful, for in case of failure they would die and escape observation.

When experimental endeavors are made to accustom animals to new kinds of food, they commonly sicken and may die. It is well-known that many things are distinctly poisonous for the higher animals. What is it that determines the poisonous or non-poisonous nature of the food?

There is scarcely an organic poison known upon which some living thing may not feed with impunity. Tobacco, for example, is intensely poisonous to most mammals, birds, insects, and arachnids, yet the growing plant is so constantly attacked by the caterpillar of a large moth that the farmer must look at his plants every day to see that the leaves are not eaten and made unmarketable. The dried leaves lacking the water of the growing plant contain a relatively greater proportion of the poison, yet constitute the regular food of the larva of a beetle. Manufactured tobacco and cigars are not infrequently ruined by being drilled with holes by them. How do these insects escape injury, grow and thrive upon a

plant whose juices furnish one of the best insecticides known? Can it be referred to habit? Are we justified in supposing that at some time when both insects and plants were evolving toward the forms in which we now know them, and the plant perhaps contained less nicotine, a symbiosis was formed which, continuing until the present time, affords these interesting examples of freedom from intoxication? It would be of interest if this were so, but it may be an entirely erroneous assumption, for the insects may suddenly have taken to the tobacco plants and for other reasons have remained unharmed.

In considering these topics we must not forget that even lowly animals are provided with organs of special sense and that disagreeable impressions received from otherwise desirable foods may keep them away. Upon such grounds may the careful avoidance of certain apparently useful foods be partly accounted for. It may have been that at some period of famine, the repugnance to the odor or taste giving place to necessity, the caterpillar of the sphinx was driven to the tobacco as the only available food, to which it became accustomed and upon which it has remained.

If it could be shown that habituation was able to effect the tolerance shown to the poisons upon which certain animals feed and was at the foundation of the physiologico-chemical difference between them and other animals not possessing such tolerance, it would aid us in our study of the problems of immunity and infection. Habituation plays a large part in what is called acquired immunity. Need the reader be reminded that men commonly habituate themselves to tobacco and opium and acquire a tolerance to these poisons far beyond that generally shared by their kind?

Unfortunately, the phenomena of infection and immunity are incapable of reduction to general principles in the present state of knowledge.

In looking over the field we first find the condition known as *Natural Immunity* in which, for no reason that

can be determined, certain animals are exempt from the injurious effects of poisons or from invasion by certain microparasites.

Remembering the suggestions concerning the habituation of animals to poisonous foods and the immunity they seem to enjoy in consequence, we turn to another aspect of the problem.

Are microorganisms subject to the same ill effects experienced by the higher organisms when the quality of their nourishment is altered? Can this be the explanation of the rapidity with which they invade the body of one host and die out in that of another? It seems justifiable to apply the same method to both, and by doing so their behavior under certain conditions will be explained.

It is much more satisfactory to consider the subjects immunity and infection with reference to the host, though to lose sight of the microparasite and of the reciprocal relations of host and parasite will be to lose much that is of fundamental importance. Indeed, almost everything that is said of one applies with equal force to the other.

Experiments with the bacteria have shown that they quickly accustom themselves to certain hosts. Thus, streptococci by special manipulations may be made so virulent for rabbits that a mathematical calculation may show that *a single coccus* may be fatal. At the same time, however, they may not increase in virulence for other kinds of animals. Not only do they become habituated to a certain kind of animal, but there is evidence to show that they may even become habituated to some particular organ of the animal; thus, streptococci taken from a lesion of the kidney of an animal and injected into the circulation of a new animal of the same kind are said to colonize in greater numbers in the kidneys than elsewhere in the body.

Here we seem to have definite, though not necessarily fixed results following habituation.

Taking a preview of the field of natural immunity, we find that there are many instances of tolerance to poisons. Thus in addition to such cases as the tobacco worm and its vegetable food, we find the mongoose and hedgehog fairly immune to the venoms of the serpents they kill and eat. If we take care for study the toxins separated by filtration from cultures of certain bacteria, we find that the rat is immune against diphtheria toxin and the hen against tetanus toxin.

Here the limits of the habituation theory are exceeded, for it is as impossible to connect the rat with diphtheria and the hen with tetanus as it is easy to connect the mongoose and hedgehogs with venom.

In regard to infection, the same general facts are true. There are certain infections of plants not known among animals; there are certain infections peculiar to the lower animals—hog cholera, swine-plague, chicken cholera, mouse septicæmia, quarter evil, etc.—against all of which human beings are immune; there are certain diseases of man—scarlatina, varicella, whooping-cough, yellow fever, etc.—against all of which the lower animals are immune; and there are certain diseases—anthrax, tuberculosis, glanders, actinomycosis, etc.—to which both man and the lower animals are susceptible.

We are in the habit of speaking of certain diseases as peculiar to certain animals, which of course means that other animals are immune. Thus if one speaks of glanders, the horse and ass are at once thought of and the possibility of human infection may be considered, but no one thinks of cattle, sheep, dogs, or fowls because it is well known that they are immune.

In all cases of such natural immunity, whether it be shown by exemption from the ill effects of toxins or by exemption from invasion by microparasites, we find it common to all of the animals of the kind. It is an exemption of a whole group, not of an individual, and it bespeaks some kind of physiologico-chemical peculiarity antagonistic to the particular microparasites against which they are immune.

It is a mistake to think of immunity with reference to physical similarity or dissimilarity. The glanders bacillus finds the white mouse immune, but the field mouse the most susceptible of all animals. The differences between these two species of mice do not appear great. It is also impossible to connect the immunity of the white mouse with any habituation it or its ancestors may have enjoyed.

It is difficult to make generalizations concerning natural immunity because of its relative character. What do we mean when we say that an animal is immune? The rat has been declared immune against diphtheria; it resists infection, is not injured by several thousand times as much filtered culture (toxin) as will kill a guinea-pig, but may be killed if the quantity of toxin injected into it be out of all proportion. The case of the hen is similar; it resists infection with the tetanus bacillus, resists the injurious effects of reasonable amounts of its toxin, but may be killed if the quantity of toxin injected into it be extreme. The mongoose suffers but little from a snake bite such as would destroy a rabbit and is therefore said to be immune against venom but it may be killed if overwhelmed by the poison. Thus we see that the tolerance is in many cases relative and not absolute.

In *acquired immunity* we have to do with an ability to endure intoxication or to resist infection that has been acquired by an individual of a naturally susceptible kind. It is a peculiarity of the individual not shared by his kind. It is acquired through circumstances arising during his own lifetime, and is neither inherited from his antecedents nor transmitted to his descendants.

Numerous examples of acquired immunity occur in the experience of most persons. In childhood most of us pass through the throes of measles, chicken-pox, whooping-cough, scarlatina and mumps, and these diseases we do not expect to have again, because they usually leave acquired immunity that persists through-

out an ordinary lifetime. Our parents probably suffered from the same affections, but we did not profit by their sufferings, and our children shall not profit by ours. Most of us have been vaccinated and thereby acquired immunity against small-pox, but do not transmit it to our descendants.

Acquired immunity, therefore, appears to be something within the province of experiment and about which much may be learned. It is also a practical matter, for means by which immunity against the infectious diseases may be acquired and these diseases prevented is of the utmost importance to society.

By what means can immunity be acquired? The answer to this question is, by *habituation.* In discussing the elementary characteristics of living matter it was shown that reaction to stimulation becomes less pronounced the more frequently the stimulations are repeated, provided such stimulations are not of an intensity injurious to the protoplasm or produced by stimuli destructive in quality. In many cases the failure of the irritable response is due to fatigue or exhaustion; in other cases it may be due to habituation. That is, the stimulant having proven less harmful than at first appeared, an adjustment is effected by which subsequent contacts produce diminishing effects. This habituation of the cell to repeated stimulation and the consequent diminution of the reaction may be fundamental in explaining acquired immunity.

The phenomena of immunity embrace two different series of reactions, one of which is directly referable to the cells, which participate actively, the other indirectly referable to the cells. The former are directed toward the destruction of the organized living entities—microparasites,—the latter toward the destruction of their chemical poisons (toxins).

Let us first consider the reactions of intoxication. It is well known that by frequent administration and cautious increase in the dosage, tolerance can be estab-

lished to certain mineral poisons, such as arsenic, and to many alkaloids, such as morphine, strychnine, and nicotine. No other explanation is at hand than that this depends upon the general principle that habituation to the poison diminishes the tendency of the protoplasm to become influenced by it. In these cases the tolerance is usually very limited, and any sudden increase in the dosage may be followed by death. The phenomena attending such tolerance are essentially dissimilar from those following habituation to the microorganismal toxins, which are chemically different, being colloidal and protein in nature.

It is not improbable that the different reactions of the organism toward the protein poisons, the toxalbumins and toxins, depend upon the closer resemblance such compounds bear to substances concerned in the nutrition of the cells. At all events, when an attempt is made to habituate the organism to the microorganismal products, greater success attends, and it is found that each administration is followed by a definite reaction which results in a definite change in the physiologico-chemical relationships.

Suppose, for example, an experiment be performed with the venom of the cobra. If this poison, which is a toxalbumin and of which a minute quantity is fatal when injected beneath the skin or into the circulation, is swallowed by a healthy warm-blooded animal, no harm is done, presumably because it undergoes digestion in the stomach and intestines and is thus rendered harmless. When it is injected beneath the skin in doses so small as not to produce death, the animal is made ill, presents a definite train of symptoms, recovers, and may then be injected with a much larger dose. After a second illness or reaction, from which it is permitted to recover, a still larger quantity may be administered with similar effects, and so on until perhaps a thousand times as much may be given without injury as would have killed it as a first dose.

This kind of treatment, known as *immunization*, is entirely artificial and it is doubtful whether anything like it can occur in nature. It leads, however, to a physiologico-chemical change in the experiment animal for its blood is now found to contain a new substance by virtue of which the poisonous power of the venom is neutralized so that if some of the venom and some of the blood serum be mixed together and injected into a new animal, no effect is noticed if the mixture be made in proper proportions. Not only is this true with regard to one fatal dose, but for multiples of that dose, so that twice the fatal dose, with twice the necessary quantity of the neutralizing serum, or five times the fatal dose, with five times the quantity of the neutralizing serum, or perhaps even one hundred or one thousand fatal doses with one hundred or one thousand times the quantity of the neutralizing serum may be administered without injury. Thus as the result of the reactions wrought by the venom, an antidote or neutralizing substance has been produced.

Substances capable of effecting reactions attended by such results are known as *antigens*, the substances resulting from the reactions as *anti-bodies*.

Antigens embrace a great variety of substances, many of which appear quite inert or harmless, as white of egg, milk, peptone etc., yet all of which are capable under certain circumstances of bringing about systemic alterations, some of which must be profound.

Thus, the blood serum of the horse when injected into guinea-pigs is harmless. An ordinary adult guinea-pig may safely be injected with 10 c.c. or even 20 c.c. without danger to life. Or guinea-pigs may be given small doses—1 c.c.—every few days for an indefinite period without harm; but if the manipulation be modified, most unexpected and extraordinary results may follow. Thus, suppose the guinea-pig be injected, into the peritoneal cavity, with 1/250 c.c. of the horse serum and then neglected for about two weeks. No effect can be

noted after the injection: the animal appears well, continues well, and shows no sign of having experienced any disturbance. It has, however, undergone a profound constitutional change in which the physiologico-chemical balance has been completely upset, for if it be now given a second injection of only 0.1 to 0.2 c.c. of the same serum, it within a few moments becomes greatly distressed, seems to suffer from embarrassed circulation, violently scratches the face and nose, gasps for breath, falls upon its side more or less convulsed, and may die within an hour. This condition is ascribed to a *hypersensitivity* to the horse serum effected by the first or *sensitizing* dose, and is described as *anaphylaxis.* Thus the single large dose is not followed by visible effects; frequent small doses, coming one after another too frequently to permit anaphylaxis, result in immunity to the ill effects; but the second dose, properly spaced after the sensitizing dose has effected its disturbance, is fatal. The nature of the anaphylactic reaction is not understood, but the disturbances resulting from it are profound and are accompanied by histological alterations affecting many of the tissues of the animal and abundantly explaining its death.

Reactions of this kind are effected by many heterologous protein substances, though they are rarely so profound or so serious as in the case chosen for illustration.

The quality of the antigen determines the nature of the antibody formed by the reaction following its administration, and in order that the full force of the antigen may be effected it is usually necessary that it be admitted to the blood directly by absorption from the subcutaneous tissue or from one of the serous cavities rather than by introduction into the alimentary tract where it is apt to be transformed and rendered inert.

The reader must not jump to the hasty and erroneous conclusion that any heterologous substance may serve as an antigen, and produce antibody formation. Only

those substances are antigens that are capable of effecting the essential physiologico-chemical reactions upon which the antibody formation depends. The number of antigens is, however, large, and they form a highly miscellaneous collection, embracing bodies usually looked upon as inert or inoffensive, bodies highly poisonous, and even formed bodies, such as various cells—red blood corpuscles, tissue comminutions—and even the microparasites themselves.

In all of the cases the antigen stimulates the formation of an antibody inimical to itself. If it be a toxin, to the formation of a neutralizing body or antitoxin; if it be enzyme, to the formation of an antienzyme; if a cell or formed body, to the formation of a cytotoxin or cell-dissolving body. Thus the antibody is always specific; *i.e.*, reactive upon its antigen alone.

The presence of the respective antibody in its blood confers increased resisting powers upon the animal in whose blood it is, hence its acquired immunity. In rare cases the immunity disappears and the animal develops a mysterious hypersensitivity not accounted for by anaphylaxis as ordinarily understood.

By long-continued immunization of large animals to certain antigens, such as diphtheria toxin, tetanus toxin, venom, etc., we may be able to secure sufficient quantities of antibodies—antitoxins—to be made practical use of for the treatment of the respective intoxications—diphtheria, tetanus, and snake bite.

The reaction between antigen and antibody is chemical in nature, but varies in quality. The reaction between toxin and antitoxin is direct and immediate; that between the antigens and the various cytotoxins indirect or intermediate—*i.e.*, taking place only in the presence of a third substance.

Such indirect chemical actions are in perfect accord with other physiological processes, and the reader will recall that pepsin can only act upon proteins in the presence of HCl; trypsin upon proteins only in the pres-

ence of enterokynase; that rennet coagulates casinogen only in the presence of calcium salts, and the coagulating ferment of the blood transforms fibrinogen only in the presence of a calcium salt.

The indirect reactions are chiefly known in reference to the solution of formed bodies—cells, etc.—and were first studied with reference to the hemolysis or the solution of red blood corpuscles by immune hemolytic serum.

Such a serum may be prepared by defibrinating blood, sedimenting the corpuscles with the aid of a centrifuge, pouring off the plasma, adding an equal volume of physiological salt solution, shaking up the corpuscles so as to wash them, recollecting them by means of the centrifuge, decanting the solution, replacing it by a similar volume of salt solution, again shaking the corpuscles in the fluid, and repeating the process once more. After being thus washed, and finally distributed through a small quantity of salt solution, the suspension is injected into the abdominal cavity of a rabbit. The best treatment seems to be to administer about six doses, increasing from 3 to 6 c.c., the injection being made bi-weekly, always with fresh material. In getting rid of these corpuscles, which act as an antigen, an antibody known as an *immune body* or *amboceptor* is formed. By French writers, for reasons later to be explained, it is also known as the *fixateur* or *substance sensibilisatrice*.

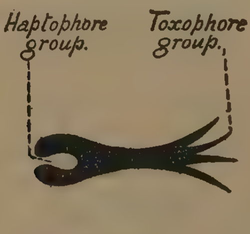
When washed red corpuscles, prepared as has been described, but in a 5 per cent. suspension in physiological salt solution, are added to diluted blood serum from an animal treated as has been suggested, and therefore containing the specific amboceptor, scarcely any change will be noted, and if the amboceptor serum have been previously heated for an hour to 55° C., no result at all will be effected. If, however, to the mixture that thus appears to be indifferent there be added a small quantity of the blood-serum of a freshly killed guinea-pig, the corpuscles quickly hemolyse and dissolve. Upon investigation, the blood serum of the normal guinea-pig is

found to contain the third element required, which is known as the *complement.* This complementary substance is, therefore, something normal to the blood, whose presence does not depend upon any experimental manipulation and is not capable of effecting any change

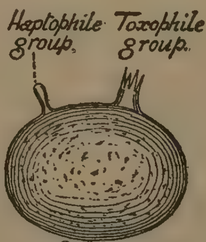
cl. *a.* *c.*

FIG. 128.—Diagram illustrating the factors concerned in hemolysis, cytolysis, and bacteriolysis. *cl,* The cell to be dissolved; *c,* the complement or solvent by which it is to be dissolved; *a,* the amboceptor or intermediate body by which the two can be brought together.

in the blood corpuscles by itself. It is, however, activated by the amboceptor. If the process of hemolysis by complement and amboceptor is to be thoroughly understood, it may be well to visualize it in a manner shown in the following diagram:



Toxin.
FIG. 129.

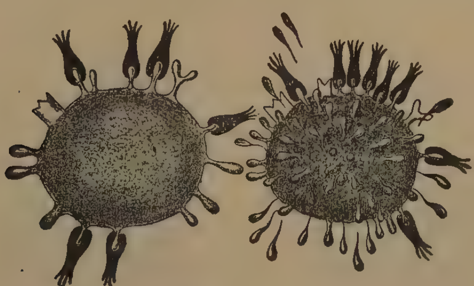


Cell.
FIG. 130.

It is now apparent why the amboceptor is so called, for it is shown to take hold of the complement on one hand and of the corpuscle on the other. It will become clear why the complement, or solvent, an enzymic substance, is unable to accomplish anything by itself, not being able to connect with the corpuscle, and why the

to absorb its customary nutrient molecular groups, which are interfered with by the presence of the toxin molecules, which, though adapted for combination with the receptors, are of no use to the cell. To prevent starvation the cell is supposed by Weigert and Ehrlich to compensate by the regenerative formation of additional receptors to meet the emergency.

The period of "reaction" following the injection of the antigen corresponds to the time during which the cells are thus overcoming the embarrassment and providing themselves with the needed receptors. As the injections of the antigen are repeated and the doses in-



FIGS. 133 AND 134.

creased, the number of new receptors to be formed becomes greater and greater, and the habit of regenerating them so effectually established that they form in excess of all requirements, and being superfluous detach from the cell and occur free in the lymph and blood. These free receptors retain their haptophilic affinity and their haptophorous adaptation, so that should adapted haptophiles be present they combine with them in the blood, before they are able to reach the cells, or being present in the drawn blood confer upon it the future power of combining with the toxin molecules rendering the toxin inert when injected, after the combinations have been effected, into some new animal.

are absent. The type of epithelium in the new covering conforms to that originally present, squamous cells being formed where squamous cells pre-existed, columnar cells, where columnar cells pre-existed.

2. *The Fibrillar Connective Tissues.*—When the injury or disease has involved a greater depth of tissue, the fibrillar connective tissue manifests activity and soon shows itself to be the most important factor engaged in the process of repair. Its cells multiply, pass through stages analogous to those seen in the formation of the areolar tissue of the embryo, and eventually produce fibres of collagen and fibroglia, by which the wound is at first more or less completely closed and subsequently drawn together. Newly formed tissue of this kind is known as *cicatricial tissue* and constitutes the "scar." It at first appears in excess, but subsequently contracts more and more, loses its cellular character, and becomes more and more densely fibrous until the separated edges of the wound are more or less closely approximated and strongly bound together. In freshly repaired wounds one sees through the delicate newly formed epiderm, a mass of pink scar tissue which becomes whiter and less conspicuous as time elapses.

3. *The Blood Vessels.*—As growing tissues, such as form the new scars, require to be nourished during the period of active growth, new capillaries, arterioles, and venules are formed to meet this requirement. Capillaries are formed as filamentous offshoots from pre-existing capillaries. These increase in size and gradually come to consist of several endothelial cells which become channeled. Arterioles and venules are formed by enlargement of capillaries whose walls become supported by fibrillar and muscular tissues that extend over them from the larger vessels. Such new vessels may be permanent or may be of temporary use only and subsequently disappear through the pressure exerted upon them by the contracting fibrillar tissue as the repair becomes more and more perfect.

4. *Bone.*—In all animals fractured bones are perfectly repaired in uncomplicated cases. As, however, the osseous tissue is inelastic, it is essential that the member to which the bone belongs shall be kept absolutely quiet, else instead of a bony union, only a fibrous union will take place and a false joint or *pseudarthrosis* be formed. In the process of repair, the osteoblasts derived from the periosteum or surrounding membrane are the formative cells. They first elaborate a temporary or provisional tissue of a nondescript character, known as *callus.* It much resembles the hyaline cartilage with centres of ossification seen in embryonal bone formation, and as it calcifies is, like it, without Haversian systems and not distinctly laminated. This tissue is the crude material upon which the bone cells subsequently work as the callus is reconstructed and rearranged so as to bring about complete continuity of the injured bone, after which the surplus is removed. The *provisional callus* surrounds the ends of the broken bone with a spindle-shaped mass of tissue which acts the part of a splint until the true or *definitive callus* which forms the permanent bond of union is formed, after which it is absorbed.

The union of the bones and the restoration of function usually requires but a few weeks, but the final removal of the redundant callus and the restoration of the symmetry of the bone is not perfected for years.

As the bone is a product of the periosteum, the loss of much bony tissue in consequence of disease is not incompatible with its regeneration if the periosteum is not destroyed or too much injured, and it is not unusual for surgeons to strip off a fairly healthy periosteum from a diseased bone, remove the bone, and subsequently find a fair substitute manufactured by the carefully preserved membrane.

5. *Cartilage.*—Damage to cartilage is usually repaired by the intermediation of fibro-connective tissue by which the fragments are held together, no new cartilage being formed.

The antitoxic nature of the immune serum is thus referable to the liberated superfluous receptors with which the blood serum of the immunized animal becomes more and more thoroughly charged as the immunization process is pushed to its maximum point.

A brief consideration of the subject will show that the natural immunity of any animal may depend upon its cells being without haptophile groups, or receptors, with the necessary adaptations to the toxic haptophores, or being without toxophilous receptors by which the actual poisonous combinations can be effected. It also explains acquired immunity through regeneration of the haptophile groups, and the occurrence of the antitoxic

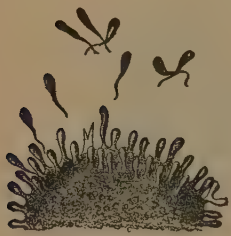


Fig. 135.

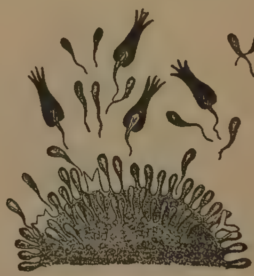


Fig. 136.

quality of the blood of the immunized animals through the liberation of the superfluous receptors into the blood.

The theory is ingeniously modified to explain those different reactions that follow the employment of an antigen consisting of organized bodies. To meet this requirement it is assumed that there is a second order of receptors possessing double affinities, attracting on one hand the molecules useful to the cell, and on the other the enzymic substances by which they may be utilized:

Such receptors, later detached and circulating in the blood, may be recognized as the *amboceptors* through whose affinity for the complement on the one hand and for the formed elements of the antigen on the

other the interaction resulting in solution or cytolysis is brought about.

It seems unnecessary to pursue the ramifications of the theory. It is a very pregnant one and has been of inestimable value in enabling physiological chemists to grasp the facts where, the true chemistry of the reactions being unknown, it might not have been possible to follow them along conventional lines.

But it will be remembered that our study of the problems of immunity began with the resistance of certain organisms to microparasites by which others are successfully invaded and destroyed, and though these microorganisms were mentioned as the chief factors for consideration, a digression was made in order that the facts appertaining to immunity from intoxication might be thoroughly in mind, for it is almost axiomatic that ability to resist infection implies ability to endure the toxic products of the microparasite.

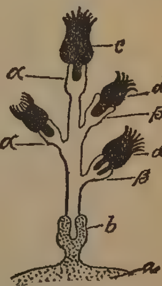


Fig. 137.—Surface of a cell with a receptor of the second order fitted to combine on one hand with *a*, an albuminous molecule, and *b*, an enzymic molecule. (*Ehrlich and Marshall.*)

We may therefore be justified in supposing that when an immune animal is found to destroy microparasites in its body, it must be indifferent to their toxic products. Its cells experiencing no injury are free to attack and destroy the invading microorganisms.

The destruction of the microparasites in immune animals is effected in two ways: 1, by the activity of the phagocytic cells which devour them; 2, by solution in the body juices. Both methods are usually observed, though the former is most frequent in naturally immune animals, the latter in animals with acquired immunity.

Though perhaps not first observed by him, phagocytosis was first suggested by Metchnikoff as the chief

defense of the body against infection. His original observations were made upon certain water fleas invaded by a fungus. In those cases in which the microparasite was overcome, the phagocytic cells of the little animal were so active that he attributed its salvation to them.

Through years of patient investigation Metchnikoff and his followers have brought together a tremendous array of facts in support of the theory of phagocytosis, and have entrenched themselves behind such an array of evidence as to be almost unassailable.

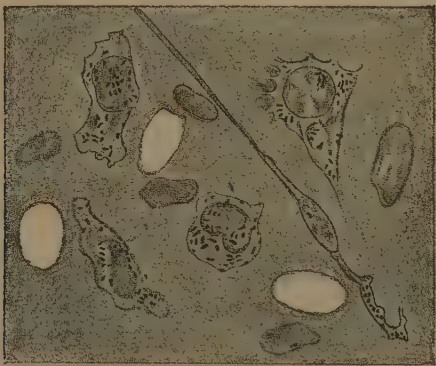


Fig. 138.—Phagocytosis; the omentum, immediately after injection of typhoid bacilli into a rabbit. Meshwork showing a macrophage, intermediate forms, and a trailer, all containing intact bacilli. (*Buxton and Torrey.*)

The theory naturally underwent many modifications as necessity for them arose, but throughout the years of enthusiastic appreciation that followed the development of the lateral chain theory, Metchnikoff has remained unshaken in the belief that the reactions of immunity are simple and has continued to maintain that they are all finally referable to the phagocytes.

It becomes imperative, therefore, that the *theory of phagocytosis* be carefully examined in order that its merits as explanations of the phenomena of immunity can be estimated. As originally conceived, phagocytosis

implied that the cells of the host, especially the white corpuscles of the blood, took the microparasites into their substance and destroyed them just as an amœba takes up many small objects, digests, and dissolves them.

An investigation of the leucocytes of immune animals shows that though there are notable exceptions, the blood corpuscles do behave in this manner. It is also found, though again there are exceptions, that the corpuscles of susceptible animals usually neglect the microparasites, which are therefore free to multiply; but that when such naturally susceptible animals are by any means made immune, their corpuscles change and begin to take up the microparasites.

The conditions thus corresponded fairly well with the requirements of the theory until certain additional facts were discovered.

Thus it was found by Nuttall and Buchner that bacteria are commonly killed when placed in the blood serum of an animal. This led to a new idea—that the bacteria were killed by some substance in the body juices and only taken up by the phagocytes after death had made them harmless. Many interesting and some paradoxical observations were made. Thus the bacillus of anthrax when put into the rabbit's body rapidly multiplies, distributes itself throughout the blood, reaches all the organs, and kills the rabbit. If, however, the anthrax bacilli are placed in some of the rabbit's blood drawn into a test-tube, they meet with speedy destruction. Why should this paradox occur? Why should their introduction into the rabbit's blood in the rabbit's body be followed by the death of the rabbit, but their introduction into the rabbit's blood in a test-tube be followed by their own death? This was a much debated point. Buchner and his followers named the bacteria-destroying substance of the blood *alexine*. For a while it seemed as though the doctrine of phagocytosis had received its death-blow, but Metchnikoff replied that the destruction of the bacteria by the phagocytes depended upon

enzymic substances, and that if the phagocytes were destroyed the enzymes remained in solution in the body juices. The alexine of Buchner was, in his opinion, *microcytase*, an enzyme resulting from *phagolysis*, or dissolution of the phagocytes.

By an ingenious manipulation, he contrived to place bacteria, inclosed in small collodion bags, in the body cavities of animals. These microorganisms, though exposed to the effects of the body juices, were defended from the phagocytes and multiplied abundantly, though if the bag ruptured they were destroyed by the cells.

In the meantime, the toxins and antitoxins had been discovered, and it became necessary to account for immunity against intoxication and for antitoxin formation. The theory was, however, capable of application to the new problems, for, it was argued, not only may the phagocytic cells take up formed objects, but they may also absorb fluids, and by virtue of their enzymes, digest and destroy the toxins they contain. Further, the enzymes liberated from destroyed phagocytes may be capable of acting similarly upon free toxin in the blood.

Each toxin injection administered to an animal was supposed to destroy innumerable phagocytes, with whose enzymic contents the blood became replete, hence its antitoxic character.

It was sometimes difficult to substantiate the views of the theorist, but time usually brought forth new and surprising evidences in his favor.

Two kinds of phagocytes were next found to be important, the leucocytes or *microphages*, possessing an enzyme called *microcytase*, and the tissue cells, notably the endothelial cells or *macrophages*, possessing an enzyme called *macrocytase*.

The bacteria and minute entities are taken up by the microphages, larger objects, like heterologous blood corpuscles, suspended tissue fragments, etc., by the macrophages. The action of the two enzymes is slightly different.

When the agglutination of bacteria was discovered, and observers everywhere were trying to account for the peculiar phenomenon, Metchnikoff attributed it to the action of one of these enzymes and looked upon it as a preparation of phagocytosis.

But the theory expanded most beautifully when it became necessary to account for the phenomena of cytolysis. Ehrlich's explains it as resulting from the combination of complement, amboceptor, and cell. Metchnikoff regards it as the result of the successive action of the two enzymes. One, probably the macrocystase, prepares the cell by fixing or sensitizing it, the other, the microcytase, then dissolves it. For this reason Metchnikoff never uses the term amboceptor, but speaks of that factor in cytolysis as the *fixateur* or *substance sensibilisatrice.*

When Wright discovered certain substances in the blood which he called *opsonins*, and which he believes prepare the bacteria for phagocytosis, it seemed to Metchnikoff but a new application of the fixateur.

There are, therefore, two means by which the infecting microparasites may be destroyed in naturally immune animals—the phagocytic cells and the germicidal body humors—and it makes comparatively little difference by what theories we account for their action.

We must next endeavor to find out whether the same conditions obtain in acquired immunity, but before attempting this it may be well to pause to inquire how immunity against infection may be acquired.

It has already been pointed out that there are many diseases from which one usually suffers but once. Though a few notable exceptions occur, it is well known that to have had chicken-pox, measles, scarlatina, mumps, whooping-cough, yellow fever, typhoid fever, and small-pox is to be immune against future attacks. The exceptions are of interest because they coincide with the results of experimental investigation.

In reference to all these diseases we can make the following statements:

> There are a few persons who, having been exposed to one or the other of the infectious agents, escape illness.
> There are a few persons who, having been exposed once or even several times without resulting illness, succumb upon an additional exposure.
> There are a few persons who, having been infected and suffered the illness, take it again after the lapse of a varying length of time.
> There are a great number who, having once suffered from one of these diseases, never take it again.

These general statements show that there are differences in the behavior of different individuals toward the infectious diseases. They also show that acquired immunity is less permanent and less uniform than natural immunity. Some persons acquire little immunity through infection, some soon lose the immunity, some retain it many years and then lose it, some never lose it.

Experience also leads us to believe that the permanence of immunity bears some reference to the severity of the disease; to have a disease badly may, but does not necessarily, guarantee a more thorough and more prolonged immunity than to have it very lightly.

It may be imagined that so soon as it became clear that to have a contagious disease afforded immunity from future attacks, sagacious individuals set about devising means by which practical advantage might be made of the information. Modern methods of experiment were, however, unknown, and the only possible application during many centuries was the occasional exposure of healthy persons to mild cases of the infectious diseases in the hope that they might pass through

a mild attack of the disease at a convenient time. The method could not, in the very nature of things, attain to any degree of popularity, though it is still practised to some extent, and children are sometimes during the vacation season thus exposed to chicken-pox and measles in order that they may lose no time at school.

It has been for centuries the practice of the Chinese to induce small-pox by thrusting scabs from the pocks into the noses of healthy persons or to tie them upon their persons to produce a mild attack of the disease. The method is crude and filthy and likely to result disastrously. The Turks invented an improved method, which when brought to western Europe was known as "inoculation" and was practised with good enough results to be continued until something better was discovered.

In her letter to Mrs. S. C.———, dated Adrianople, April 10, O. S. 1717, Lady Mary Wortley Montague writes upon this subject as follows: "The small-pox, so fatal and so general among us, is here entirely harmless by the invention of *ingrafting*, which is the term they give it. There is a set of old women who make it their business to perform the operation every autumn, in the month of September, when the great heat is abated. People send to one another to learn if any of their family has a mind to have the small-pox; they make parties for the purpose, and when they are met (commonly fifteen or sixteen together), the old woman comes with a nut-shell full of the matter of the best sort of small-pox, and asks what veins you will have opened. She immediately rips open that you offer her with a large needle (which gives you no more pain than a common scratch) and puts into the vein as much venom as can lie upon the head of her needle, and after binds up the little wound with a hollow bit of shell; and in this manner opens four or five veins. The Grecians have commonly the superstition of opening one in the middle of the forehead, one in each arm, and on the breast, to mark

the sign of the cross; but this has a very ill effect, all of these wounds leaving little scars, and is not done by those that are not superstitious, who choose to have them in the legs or that part of the arm that is concealed. The children or young patients play together all the rest of the day and are in perfect health to the eighth. Then the fever begins to seize them, and they keep their beds two days, very seldom three. They have very rarely above twenty or thirty in their faces, which never mark; and in eight days' time they are as well as before their illness. Where they were wounded there remain running sores during the distemper, which, I don't doubt, is a great relief to it. Every year thousands undergo this operation; and the French Ambassador says pleasantly that they take the small-pox here by way of diversion as they take the waters in other countries. There is no example of anyone that has died in it; and you may believe I am very well satisfied of the safety of this experiment, since I intend to try it on my dear little son."

The next experimental application of the principle of preventing an infectious disease by giving an attack of a disease was made by Edward Jenner, an English physicians and naturalist, once a pupil of John Hunter, in whose family he lived. For some time Jenner had been engaged in the study of small-pox, cow-pox, and swine-pox, and the development of the latter two diseases when communicated to man. He at first made the mistake of believing cow-pox to be caused by the contagion of a peculiar hoof disease of horses known as "grease." He first suggested that an attack of cow-pox would prevent small-pox, and that it might be experimentally employed for that purpose, in a conversation with William Hunter as early as 1770. A German schoolmaster, Nicholas Plett, had already held the same idea and had made certain proofs, but the matter had gone no further. Jenner inoculated his own son with swine-pox and later found him immune against small-pox. Fearing

failure and being timid by nature, it was not until May 14, 1796, that Jenner gave a public demonstration. A boy was inoculated with cow-pox, and having passed through the disease, was found upon inoculation to be immune against small-pox. In 1798, Jenner wrote a lengthy paper upon "vaccination," detailing the whole matter and stating his belief and his proofs. For a long time the medical profession as well as the laity were incredulous, but experiments were made by one after another of the prominent physicians and the method slowly spread until its advantages became so apparent that it became adopted in one after another of the European countries and finally in America, ultimately being made more or less compulsory in all countries with such striking success that small-pox, once the most frequent and most terrible of maladies, has become a comparatively rare disease in most civilized countries.

From the fact that the disappearance of small-pox has been coincidental with the disappearance of cow-pox, swine-pox, etc., and that the inoculated viruses of these diseases afforded protection against small-pox, there can be little doubt that these affections had a common ancestry, and that the mild character of *vaccinia,* or cow-pox, in man is due to some change suffered by the specific microparasites—a diminution in their virulence—resulting from their exposure to the defensive juices, etc., of the cow.

No further progress was made in the field of experimentally induced immunity from the invention of vaccination by Jenner until the time of Pasteur, nearly one hundred years.

With Pasteur, however, came a new epoch, that of the discovery of the microparasites of disease, and shortly after, through the work of Koch and Pasteur, the means of artificially cultivating and accurately observing them, and in consequence a great expansion in the knowledge of infectious diseases and in the means of preventing them.

From chemistry Pasteur was led into a study of fermentation and putrefaction which he discovered to be due to microorganismal life, the source of which he quickly traced to the spores or seeds of minute plants abounding in the atmosphere. The source of fermentation being thus traceable to living entities in the air, he conjectured that the source of fermentation in wounds might be the same, and an investigation of the discharges from fetid wounds showed them to be teeming with microorganismal life capable of infecting the small animals used for inoculation experiments. Convinced that these microbes were the cause of the disturbances, the investigation was pursued, and for various maladies different microbes were found. The first investigations bearing directly upon the subject of immunity were made with the bacillus of chicken cholera and came about in a peculiar manner. "A chance such as happens to those who have the genius of observation was now about to mark an immense step in advance and prepare the way for a great discovery. As long as the culture flasks of the chicken-cholera microbes had been sown without interruption, at twenty-four hours' interval, the virulence had remained the same; but when some hens were inoculated with an old culture, put away and forgotten a few weeks before, they were seen, with surprise, to become ill and then to recover. These unexpectedly refractory hens were then inoculated with some new culture, but the phenomenon of resistance had occurred. What had happened? What could have attenuated the activity of the microbe? Researches proved that oxygen was the cause, and, by putting between the cultures variable intervals of days, of one, two, or three months, variations of mortality were obtained, eight hens dying out of ten, then five, then only one out of ten, and at last, when, as in the first case, the culture had had time to get stale, no hens died at all, though the microbe could still be cultivated."

"Finally," said Pasteur, eagerly explaining this phe-

nomenon, "if you take each of these attenuated cultures as a starting-point for successive and uninterrupted cultures, all this series of cultures will reproduce the attenuated virulence of that which served as a starting point; in this same way non-virulence will produce non-virulence."

"And, while hens who had never had chicken cholera perished when exposed to the deadly virus, those who had undergone attenuated inoculations and who afterward received more than their share of the deadly virus, were affected some with the disease in a benign form, a passing indisposition, sometimes, even, they remained perfectly well; they had acquired immunity. Was not this fact worthy of being placed by the side of that great fact of vaccine over which Pasteur had so often pondered and meditated?"

Practical application for the prevention of chicken cholera was soon made of this observation, and it led to the next great achievement in the way of inducing immunity.

The bacillus of anthrax (splenic fever of cattle) had been discovered by Davaine, and Pasteur's great ambition was to prepare some vaccine by which its ravages might be stayed. The problem could not, however, be so easily solved, for the spores of the bacillus prevented its attenuation and preserved their original virulence after having been kept dry for ten years. Clearly some other means of attenuation must be devised. Eventually, after having tried many means of effecting the attenuation necessary for the vaccine, he found that when the microbes were cultivated at an elevated temperature—42° to 43° C.—they did not develop spores, and that when cultures so modified were subsequently cultivated at 30° C., they retained this peculiarity as well as diminished virulence.

The result of this observation was ability to produce cultures of varying degrees of virulence, which like those of the chicken-cholera microbes, bred true to their acquired virulence.

When the statement was made by Pasteur that by the use of vaccines consisting of properly selected cultures of attenuated anthrax bacilli, he would be able to prevent the occurrence of anthrax, a storm of opposition and ridicule was aroused but quickly quelled for on May 5, 1882, at the farm of Pouilly le Fort near Melun, France, he gave a large public exhibition and vaccinated twenty-five sheep, five cows, and an ox with the first virus, before a large gathering of agriculturists, physicians, and veterinarians. On May 17, the second inoculation with a more virulent virus was made. On May 31, the final test was made, and all of the animals were inoculated with a triple dose of virulent virus. On June 2 all of the many control animals were dead, but the vaccinated animals were all well and remained so.

This was the inception of a method that has saved millions of dollars to the farmers, by enabling them to protect their stock whenever anthrax makes its appearance.

Almost at the same time Arloing, Cornevin and Thomas, and Kitt applied a similar method for protecting animals from quarter-evil. The vaccine, however, was not made with pure cultures of the microbe, but by drying and heating the muscular tissue of an animal inoculated with it. The muscle contained innumerable bacilli, which attenuated when the dry muscle was heated for a time. The dry muscle thus treated was ground to a powder, suspended in some indifferent fluid, and injected with a hypodermic syringe into the animal to be protected. An injection of this kind was found to be sufficient to afford immunity. This method is also now in general use and has been of great economic value to agriculturalists.

Pasteur next extended his immunological researches to human pathology and devoted himself to *rabies*, or *hydrophobia*, a terrible disease, invariably fatal, caused by the bites of rabid animals. He found that the virus, though present in the saliva and transmitted by it,

was so hopelessly mixed with other pathogenic microorganisms of the saliva as to make it impossible to use it as the basis of exact experiments. Looking for the microbe of rabies, he found it present in greatest intensity in the nervous system, and found that by rubbing up the nervous tissue from the brain or spinal cord with physiological salt solution, it was possible to secure the virus in a form free from admixture with other microbes and convenient for experimental investigation.

Unfortunately, though there was every evidence that the disease was infectious and therefore microbic, he found it impossible either to demonstrate the specific microbe by the microscope or to make it grow in artificial culture. In regard to this it may be well to remark that we are not yet able to cultivate this microbe, though there seems to be little doubt about it being a protozoan parasite discovered by an Italian named Negri.

Disregarding his inability to demonstrate the microbe and finding that he was perfectly able to reproduce the disease experimentally, by using the emulsion of the nervous tissues, Pasteur set about finding methods of attenuating the virus. The results were most interesting. The nervous tissues of dogs and other animals with the disease were found to yield viruses of varying degrees of virulence, "*street virus*"; but after such a virus was manipulated in the laboratory by passage through a series of rabbits, it acquired a uniform degree of virulence and became known as a "*fixed virus*." Such a fixed virus, contained in the spinal cord of a rabbit, was further found to be susceptible of attenuation by drying, the degree of attenuation being proportionate to the length of the period of drying. It was not difficult to arrive at any degree of attenuation until virulence was eventually entirely lost. By working with the attenuated viruses, and administering a succession of doses with increasing degrees of virulence, animals could be immunized against the virulent "street virus."

As, of course, no one would desire to be immunized

against the disease who was in no exceptional danger of getting it, no use could be made of his method unless it could be applied to those in imminent danger—*i.e.*, who had already been bitten by mad dogs. A peculiarity of the disease is its long incubation period, which varies from one to several months. The thought occurred to Pasteur that it might be possible *to effect the immunization during the incubation period.* This method was tried with great hesitation upon a lad terribly bitten by a mad dog. "The child, going to school by a little byroad, had been attacked by a furious dog and thrown to the ground. Too small to defend himself, he had only thought of covering his face with his hands. A bricklayer, seeing the scene from a distance, arrived and succeeded in beating off the dog with an iron bar; he picked up the boy covered with blood and saliva. The dog went back to his master, Theodore Vone, a grocer at Meissengatt, whom he bit on the arm. Vone seized a gun and shot the animal, whose stomach was found to be full of hay, straw, pieces of wood, etc." This little boy, Joseph Meister, was the first to receive the treatment, though it was undertaken with great reluctance by Pasteur and only upon the advice of Vulpian and Grancher. The lad escaped hydrophobia and experienced no ill from the treatment. Other opportunities for testing the method were soon forthcoming, and it was soon evident that a new triumph had been achieved, for in all those cases that came to hand sufficiently early, the disease was prevented and in no case was harm done. The treatment is extremely simple. It consists in daily injections of emulsions of spinal cord in physiological salt solution, the cords being taken from rabbits inoculated with the "fixed virus" and dried over calcium chloride in sterile bottles. The first cord should have dried about fourteen days, the next thirteen days, the next twelve, and so on with modifications such as the experience of the operator or the necessity of the case may make desirable. The success of the method has

been so gratifying that "Pasteur institutes" for its application have been founded by governments or by large cities in nearly all parts of the world.

Another important application of this method of preventing disease by the use of modified cultures of the specific microorganisms of the disease has been made with great success by a Russian bacteriologist named Haffkine, for the prevention of cholera. In this case, the specific organism, the "comma bacillus," a spiral organism, having long ago been discovered by Koch, and being easily cultivable, the method of operating was more simple and more closely resembled the vaccinations against chicken cholera and anthrax.

The success of Haffkine probably stimulated A. E. Wright to attempt very much the same method in the prophylaxis of typhoid fever. These two methods both depend upon the employment of attenuated or killed cultures for the production of sufficient active immunity to enable the recipient to resist ordinary infection.

The same thing was later tried by Haffkine for the prevention of plague, and in all three of these diseases, cholera, typhoid fever, and plague, trials made upon large numbers of soldiers belonging to the British Army in India have shown most gratifying results.

A still further utilization of the principle has been made by Wright in the "vaccine treatment" of many of the infectious diseases. The fundamental idea being that when the disease is of prolonged duration, or of circumscribed invasiveness, the vaccination of the patient with killed or attenuated cultures of the specific organism brings about a sudden and acute reaction, followed by an increase in the general resisting power through improvement of the bacteria-destroying mechanism by which the bacteria may be overcome. Excellent results are claimed for this method in the treatment of suppurating acne, furunculosis, certain localized forms of tuberculosis, various chronic suppurating sinuses, etc.

The nature of the resisting power thus induced is

found to depend upon a combination of those factors engaged in the defense of the body. That is, there is a trace of antitoxic power in the blood in those cases in which toxic substances were embraced in the antigen; amboceptors are present when the antigen contains the essential microbes of the affection, but, above all, in all cases of active immunity against infection the phagocytic power of the leucocytes is greatly increased so that the cells, originally inactive or feebly active, become very active and hungry for the microorganisms which they greedily devour and destroy.

References,

R. Kraus and C. Levaditi: "Handbuch der Technik und Methodik der Immunitätsforschung," Jena, 1909.

Elie Metchnikoff: "L'Immunité dans les maladies infectieuses," Paris, 1901.

Ludwig Aschoff: "Ehrlichs Seitenkettentheorie," Jena, 1905.

Joseph McFarland: "The Pathogenic Bacteria," Phila, 1909. Chapters upon Infection and Immunity.

Joseph McFarland: Chapter upon "Immuno-Therapy," "Modern Clinical Medicine," volume on "Infectious Diseases," N. Y., 1910.

H. T. Ricketts: "Infection, Immunity, and Serum Therapy," Chicago, 1906.

Vallerie-Radot: "The Life of Pasteur."

CHAPTER XVI.

MUTILATION AND REGENERATION.

Regeneration is the function of repair. It embraces a number of dissimilar processes. Thus certain used-up or worn-out elements are constantly renewed and in this sense repaired. The human skin is subject to attrition by which its superficial cells are being rubbed off, but new cells are always forming to take their place; the nails are always wearing away, but are always growing from the matrix; the hairs are broken or shed, but continue to grow or new hairs to take their place. Among the birds there are periodical moults, when the old feathers that may have become broken or useless are shed and replaced by new ones. Reptiles, lizards, and snakes periodically shed the entire skin beneath which a new one has formed. Stags annually shed their horns, new ones of slightly different form being produced to take their places.

When the entire thickness of the cuticular covering is accidentally penetrated and the subjacent tissues exposed, almost every living organism is capable of effecting a repair by which the exposed surface, if not too large, becomes covered by a new protective skin. When the damage is of a more serious nature and a part of the organism torn away, the reaction that follows varies in different cases. Sometimes the injury simply heals; that is, is covered by a new protection and the mutilation persists; sometimes, as among certain cœlenterates and worms, there is a rearrangement of the remaining tissues by which the symmetry of the organism is restored though its size is diminished; and sometimes the loss of the part is followed by a new growth which gradually

moulds itself into the exact form of that which was lost and eventually comes to perform its function. So the phenomena of regeneration include simple healing, the rearrangement of the entire organism, or the restitution of the lost part.

It is easy to understand that cells are continually multiplying in the rete mucosum, in the nail matrix, or in the hair follicles, undergoing a regular series of transformations and ending, respectively, in horny epiderm, nails, and hairs, all of which are relatively simple structures; but when a peacock moults and the regenerative process is called upon to produce large, elaborately decorated, and beautifully colored feathers, each of which bears a definite relation of size and figure to the geometrically proportioned pattern of the bird's spread tail, one cannot help feeling that something more than local conditions are engaged in the new formation.

Each year the antlers of the stag are shed, but grow again as soft spongy osseous formations which become more and more dense or eburnized until of ivory hardness. Each year the antler develops along new lines, increasing in size and complexity according to the age of the stag, always in conformity with the type of the species, but never twice the same in the same individual. Here there can be no doubt about the hereditary character of the influences controlling the regeneration.

When the repair following injury is carefully considered, we again find that it is less simple than at first appears, for the closure of the wound by cicatricial tissue and its covering by a new growth of the ectoderm is complicated by a more or less pronounced tendency toward the renewal of those parts that may have been destroyed or removed.

The present knowledge of the subject is insufficient to enable the phenomena of regeneration to be reduced to orderly scientific principles; we no doubt confuse different processes with one another. The following arrangement may enable the student to appreciate

such facts as are known, and to realize the difficulties in the way of accurately comprehending them.

I. *The mutilated organism restores its symmetry by a rearrangement of its substance and recovers its size by subsequent growth.*

This is seen in lowly organisms only. Thus, when the protozoan Stentor cœruleus is cut transversely into several segments, each transforms itself into a more or

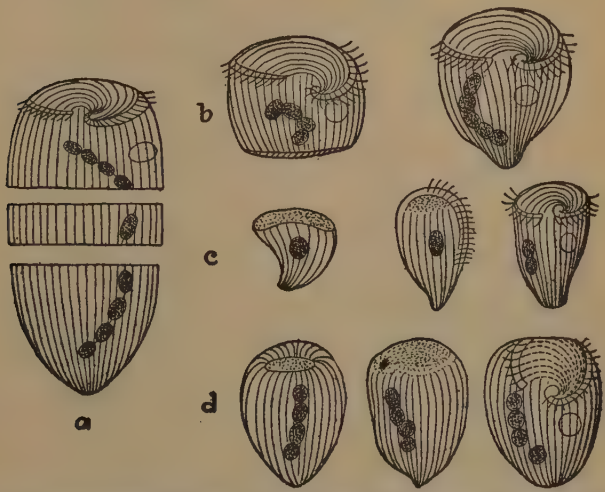


FIG. 139.—Stentor cœruleus. *a*, Cut into three pieces; *b*, regeneration of anterior piece; *c*, regeneration of middle piece; *d*, regeneration of posterior piece. (*After Gruber.*)

less perfect diminutive of the original in the course of a few hours and is then ready to grow to its normal size.

A similar adjustment is seen in Hydra. When this organism is transversely cut, the anterior half lengthens and develops a new base, the posterior half also lengthens and develops new tentacles, so that two new hydras are formed. If a fragment be cut out of the centre of a hydra by two parallel transverse incisions, the ends gradually close, until a hollow prolate spheroid is formed.

This soon becomes more and more prolonged into a cylinder, at one end of which tentacles and an oral aperture develop, the other end remaining closed to form the foot. During these transformations no food is consumed, and, therefore, no growth is possible; the adjustment must be accomplished through a rearrange-

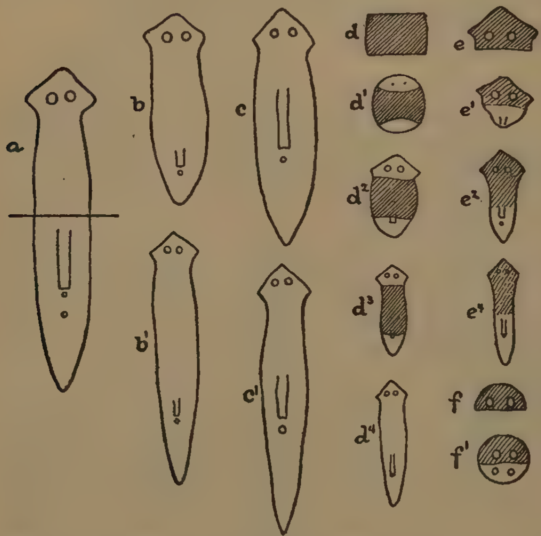


FIG. 140.—Regeneration in Planaria. *a–e*, Planaria maculata: *a*, normal worm; *b*, b^1, regeneration of anterior half; *c*, c^1, regeneration of posterior half; *d*, cross-piece of worm; d^1, d^2, d^3, d^4, regeneration of same; *e*, old head; e^1, e^2 e^3, regeneration of same; *f*, Planaria lugubris; f^1, regeneration of new head on posterior end of same. (*After Morgan.*)

ment of the structures already present. The new hydra thus formed soon grows to the normal size, however, after feeding again becomes possible.

A somewhat similar behavior is seen in mutilated planarians—unsegmented worms—which recover the normal form by the twofold process of rearrangement and growth; rearrangement predominating over growth

if the organism cannot feed, growth predominating over rearrangement if it can.

It goes without saying that this form of regeneration is only possible when the structure of the organism is relatively simple. So soon as a certain degree of complexity is reached, it ceases and multilation results either in repair or in the restoration of the lost part.

II. *The mutilated organism grows a new part to take the place of that which has been lost.*

This form of regeneration is interesting because it takes place through influences that cannot, at present, be clearly understood.

Morgan, in his book on "Regeneration," makes these divisions of the subject:

I. *Homomorphosis.*—The new part is like the part removed.

1. Holomorphosis.—The entire part is replaced.
2. Meromorphosis.—The new part is less than that lost.

II. *Heteromorphosis.*—The new part is different from that removed.

1. The new part is a mirror figure of that lost.
2. The new part resembles some other part than that lost.
3. The new part is unlike anything in the body (Neomorphosis).

Other descriptive terms used by Morgan are *Epimorphosis,* in which a proliferation of new material precedes the development of the new part, and *Morphalaxis,* in which the part is transformed directly into the part.

So far as is known, the first observations upon the regeneration of lost parts was made by Bonnet, who, in 1741, experimented with earth-worms. When he cut a common earth-worm in half, the anterior half grew new segments, forming a new tail, and the posterior half new segments and a new head, so that eventually two entire worms resulted. The regenerative capacity was

not, however, so restricted, for he also found that if he cut the worm into three, four, eight, ten, or even fourteen pieces, each piece eventually reproduced the lost segments, including the head and the tail, so that as many complete worms resulted as he had fragments of the original worm. "The growth of the new head is limited in all cases to the formation of a few segments, but the new tail continues to grow longer, new segments being intercalated just in front of the end piece which contains the anal opening." "Bonnet found that if a newly regenerated head is cut off, a new one regenerates, and if the second one is removed, a third new one develops, and in one case this occurred eight times; the ninth time only a budlike outgrowth was formed." "In other cases a new head was produced a few more times, but never more than twelve times." Short pieces removed from either end of the worm failed to regenerate, but died after a few days. Sometimes two new heads or two new tails regenerated. The polarity of the organism was always preserved; *i.e.*, the heads always grew at the anterior, never at the posterior, end.

These results of Bonnet have been confirmed again and again. The regenerated head is perfect, including the oral opening, the œsophagus, and the brain.

Morgan found that when the head of the worm known as Allolobophora fœtida was amputated, its regeneration was always perfect; that is, if one, two, three, four, or five segments are removed, exactly the same number were renewed. If, however, six or more were removed, only four or five are regenerated, so that the head is perfected, but the full number of segments behind the head is never reproduced. He found this to be the rule for all the annelids. With regard to the posterior end, he found that when it was amputated, the terminal end contained the new opening of the alimentary canal and that the new segments, of which the full complement always forms, arise in front of this terminal segment, the youngest always being the one immediately in front of it.

It is well known that the tails and fins of fishes readily regenerate when multilated or amputated. Morgan, in his lecture before the Harvey Society, cited an experiment made upon the Pacific coast for the purpose of determining whether salmon returned from the sea to the same rivers in which they were born. The fish used for the experiment, thousands in number, were marked by having a V-shaped piece cut from the tail, but as the tail subsequently regenerated the lost part, the markings were lost and the experiment failed.

Spallanzani (1768) also experimented with mutilated earth-worms, confirming what Bonnet had found; but went further, for he found that when the tail was cut from a tadpole a new tail grows to take its place. If the tadpole is fed, it grows larger while the tail is growing; if it is not fed, it ceases to grow, but a new tail is formed just the same. Further experiments showed that salamanders also regenerated amputated tails, including the vertebræ, and that if the leg of one of these animals was cut off, it regenerated; if all four legs were amputated, all four legs were regenerated, either together or in succession as they were removed. The regenerative process proceeds whether the animal be fed or not. If it is well fed, it grows larger and the lost part regenerates; if it is not fed, it grows smaller, but the leg or tail continues to regenerate just the same. It takes about as long for the perfect regeneration of the fingers or toes as for an entire limb. If a limb be amputated too close to the body, no regeneration takes place, though the wound heals. In one experiment, Spallanzani amputated all four legs and the tail of a salamander *six times* and saw them all regenerate six times during the three summer months. He also found that the upper and lower jaws of salamanders can regenerate. Lessona found that terrestrial salamanders cannot regenerate lost parts, though aquatic species of the same genus can do so. Extending these experiments still further, Spallanzani found that snails can regenerate amputated tentacles and

that certain of them can regenerate the entire head, collar, or foot.

Since the time of Spallanzani much experimental work has been done and many facts added to the knowledge of the subject, though we are still greatly in need of illumination concerning the general principles by which what is known can be correctly correlated.

We now know that lizards frequently lose their tails and regenerate them, also that the animals seem to know that they can do so, for when caught they unhesitatingly snap them off to escape. Though it can regenerate the tail, a lizard cannot regenerate the limbs or even the toes. Newts not only regenerate the tail and limbs, but also the eyes. Crustaceans—crabs and lobsters—regenerate legs, fighting claws, and sometimes antennæ and eyes. Certain arthropods—myriapods, arachnids, and a few insects—are able to regenerate lost limbs, but this power is restricted to a few species of scattered groups.

In all of these cases certain facts regarding the regenerative power must be noted. Thus, the extent of the mutilation determines whether the injured animal shall die or live as well as whether the wound shall simply heal or shall regenerate. In speaking of the salamander's legs it has already been remarked that though they may regenerate many times in succession, if the amputation be performed too close to the body, healing without regeneration results. The legs of crabs and lobsters regenerate best from a certain point known as the "breaking-joint," where the legs are constricted and weakened so that when the animal is caught and held it not infrequently frees itself by fracturing the leg at this point. If the leg be broken below the breaking-joint, the animal usually rebreaks it at that point and casts aside the intervening piece. When the leg is amputated above the breaking-joint, it is regenerated with greater difficulty. Centipedes, tarantulas, and walking-stick insects are found to have "breaking-joints," and these

arthropods regenerate their limbs when broken there. Cockroaches regenerate the tarsi, but not the leg above the tarsi.

The regenerative power appears to be greater in proportion to the youth of the animal. Embryos, larvæ, and young animals are much better able to regenerate lost parts than are fully formed and old animals. The tadpole may regenerate a tail or a limb, but the frog very rarely and imperfectly regenerates any lost member. When legs are cut off of caterpillars, they are sometimes regenerated during the pupa stage, so that the imago has the full complement.

Temperature has a marked effect upon the regenerative function. Most of the animals possessed of regenerative powers are "cold-blooded," when cold they are inactive; when warm their metabolic functions accelerate, so that if they are kept warm or the experiments performed in the summer time, regeneration is accelerated.

Lastly, complexity of structure has something to do with the regenerative function. When one sees that the power is highly developed among the lower vertebrates and that complexly organized members, such as salamanders' legs and eyes, can be correctly reproduced, he hesitates to dwell upon this point. Why should the lizard regenerate its tail and not its legs; why should the salamander regenerate its tail, legs, and eyes, but not its head; why should certain birds be able to regenerate the upper mandible, but not the limbs? These are difficult questions that cannot be correctly answered in the present state of knowledge. An attempt has been made to regard the regenerative function as a matter of adaptation by which those organisms most apt to be mutilated have become equipped for the emergency by an unusual activity of the reparative function. In support of this theory, the breaking-joint of the arthropod leg is urged as a cogent argument.

Much interest attaches to the nature of the influences governing the reparative process. The newly formed

part usually reproduces the lost part, but sometimes reverses it. Sometimes a mistake is made and a wrong part produced as when attempted regeneration of a crab's eye terminates in an antenna-like structure instead.

Nothing of the amputated salamander's hand remains to guide the growing tissues, yet a new hand complete in all its parts is formed. It is as mysterious as the phenomena of heredity—yes, more so, for it seems more easy to conceive that the ovum contains forces which by acting and reacting upon one another may attain to a finished product than that that product once finished shall be able to restore itself when mutilated. The process of regeneration, however, bears every evidence of being dominated by hereditary influences, for that which grows upon the amputated stump of the salamander is a salamander's limb, not a lizard's tail or a mollusk's eye. Spencer, Darwin, and all the writers upon heredity have found it necessary to include the phenomena of regeneration among those for which heredity must account, and see in it additional evidence that the particular kind of physiological units to which they attribute the hereditary influences must be disseminated throughout the body.

But another curious fact awaits consideration. If the lost part be replaced by a similar part removed from another creature of the same kind, the regenerative function is inhibited. The new part is accepted in lieu of the old one, grows fast by the process of healing, and a short cut to the desired end, the restoration of symmetry, is accomplished. By virtue of what impression is the suspension of regeneration brought about in such cases? How can the creature or any of its parts know that it need not grow a new limb because some accident has already furnished one? Why is it satisfied with one ready made instead of making the new one itself? These are problems difficult of solution, the answers to which may never be known. The matter

becomes still more difficult if the adaptation theory be entertained, for, granting that regeneration be an adaptation, the failure of regeneration in those cases where the new limb is substituted for the amputated one never can be so regarded, seeing that the imagination can scarcely entertain such a thought as that of mutilated animals finding adapted parts with which to replace those lost and so doing away with the necessity of preparing them.

Though the regenerative phenomena extend throughout the different phyla of animals, examples being found among such vertebrates as fishes, batrachians, reptiles, and birds, it does not extend to the mammals. No authenticated cases are on record in which parts lost by mammals have ever been regenerated. These highest and most complex of living organisms are unhappy in being without so useful a function. Among them all that can be hoped for is that healing may follow injury.

III. *The Mutilated Organism Repairs Itself Without Restoring its Symmetry.*—This method of repair has several times been referred to as "simple healing." It takes place through proliferative activities of the simpler epithelial and connective tissues. It also includes restoration of a few damaged tissues, so as to be regenerative in tendency.

1. *Epithelial Tissues.*—Whenever the covering epithelium is removed by accident or destroyed by disease, repair soon begins through the proliferation of cells at the periphery of the denudation. The multiplying cells extend more and more until, if the denuded area is not so great as to occasion the death of the individual, or so infected as to destroy the cells as they form, a new covering is produced. This new integument usually lacks the appendages with which the original structure may have been provided. Thus in repair of the skin, the hair follicles, sweat and sebaceous glands are usually absent or very few, and in the mucous membranes the glands

are absent. The type of epithelium in the new covering conforms to that originally present, squamous cells being formed where squamous cells pre-existed, columnar cells, where columnar cells pre-existed.

2. *The Fibrillar Connective Tissues.*—When the injury or disease has involved a greater depth of tissue, the fibrillar connective tissue manifests activity and soon shows itself to be the most important factor engaged in the process of repair. Its cells multiply, pass through stages analogous to those seen in the formation of the areolar tissue of the embryo, and eventually produce fibres of collagen and fibroglia, by which the wound is at first more or less completely closed and subsequently drawn together. Newly formed tissue of this kind is known as *cicatricial tissue* and constitutes the "scar." It at first appears in excess, but subsequently contracts more and more, loses its cellular character, and becomes more and more densely fibrous until the separated edges of the wound are more or less closely approximated and strongly bound together. In freshly repaired wounds one sees through the delicate newly formed epiderm, a mass of pink scar tissue which becomes whiter and less conspicuous as time elapses.

3. *The Blood Vessels.*—As growing tissues, such as form the new scars, require to be nourished during the period of active growth, new capillaries, arterioles, and venules are formed to meet this requirement. Capillaries are formed as filamentous offshoots from pre-existing capillaries. These increase in size and gradually come to consist of several endothelial cells which become channeled. Arterioles and venules are formed by enlargement of capillaries whose walls become supported by fibrillar and muscular tissues that extend over them from the larger vessels. Such new vessels may be permanent or may be of temporary use only and subsequently disappear through the pressure exerted upon them by the contracting fibrillar tissue as the repair becomes more and more perfect.

4. *Bone.*—In all animals fractured bones are perfectly repaired in uncomplicated cases. As, however, the osseous tissue is inelastic, it is essential that the member to which the bone belongs shall be kept absolutely quiet, else instead of a bony union, only a fibrous union will take place and a false joint or *pseudarthrosis* be formed. In the process of repair, the osteoblasts derived from the periosteum or surrounding membrane are the formative cells. They first elaborate a temporary or provisional tissue of a nondescript character, known as *callus.* It much resembles the hyaline cartilage with centres of ossification seen in embryonal bone formation, and as it calcifies is, like it, without Haversian systems and not distinctly laminated. This tissue is the crude material upon which the bone cells subsequently work as the callus is reconstructed and rearranged so as to bring about complete continuity of the injured bone, after which the surplus is removed. The *provisional callus* surrounds the ends of the broken bone with a spindle-shaped mass of tissue which acts the part of a splint until the true or *definitive callus* which forms the permanent bond of union is formed, after which it is absorbed.

The union of the bones and the restoration of function usually requires but a few weeks, but the final removal of the redundant callus and the restoration of the symmetry of the bone is not perfected for years.

As the bone is a product of the periosteum, the loss of much bony tissue in consequence of disease is not incompatible with its regeneration if the periosteum is not destroyed or too much injured, and it is not unusual for surgeons to strip off a fairly healthy periosteum from a diseased bone, remove the bone, and subsequently find a fair substitute manufactured by the carefully preserved membrane.

5. *Cartilage.*—Damage to cartilage is usually repaired by the intermediation of fibro-connective tissue by which the fragments are held together, no new cartilage being formed.

6. *Muscular Tissues.*—It is improbable that the muscular tissue of the mammals undergoes any effective regeneration after injury. Wounds of the unstriated muscle of the uterus and intestines repair through intermediate fibro-connective tissue cicatrices. Wounds of cardiac and voluntary muscles usually do the same, though peculiar formations sometimes appear at the injured ends of the voluntary muscle fibres which many interpret to mean that regenerative attempts are in progress. However this may be, the attempts are abortive, little new formation results, and such tissue of supposedly new formation as may be found at the ends of the fibres is distinctly atypical.

7. *The Nervous Tissues.*—It is not known that the nerve cells can be replaced when destroyed, but the nerve fibres regenerate quite well. The process is not perfectly understood. When a medullated fibre is cut or torn the proximal end degenerates to the next higher "node of Ranvier," and that of the distal end appears to degenerate altogether. If there is no infection or other unfavorable condition to prevent it, the regeneration of the nerve begins within a few days by an outgrowth from the proximal end. Such outgrowths from the axis cylinders of the proximal ends grow down in the path of the medullary sheaths, extend through whatever cicatricial tissue may be in process of formation, and on to the distal fragment. When these growing axis cylinders are able, as the result of a neurotropic influence, to find their way into or along the old sheaths, the progress toward the completion of the conducting tract is rapid, otherwise it is slow and more complicated and perhaps less perfect in the end. Some observers deny that the distal fragment degenerates completely, but think that, like the proximal end, it only degenerates a short distance so that the growing proximal end need not renew the entire path of conduction, but only so much as has been destroyed. Others think that the axis cylinder fibre is restored through the activity of

the proliferated cells of the sheath and is not a new growth from the old axis cylinder.

It is thus seen that mammals have very slight powers of regeneration, though some evidences of the new formation of important tissue elements are to be found in most cases of "simple healing."

IV. *Lost Viscera are Regenerated.*—There can be little doubt but that complexity of organization plays an important part in this event, for the more complexly the organism is constructed, the greater is the mutual dependence and indispensability of its organs.

To an organism with scarcely any viscera, those it possesses may not be so essential that life may not be easily maintained for a considerable time without them, thus affording opportunity for new organs to form. Such a condition is seen, for example, in certain sea-cucumbers, or holothurians, which when roughly handled eviscerate themselves, yet live on and subsequently regenerate a new set of organs. Were it not for the fact that the holothurian can live for a long time without organs, it could not recover from the injury. In all cases in which an organ is found to regenerate—brain of the snail, eye of the newt, etc.—the animal must be able to dispense with that organ during as long a time as its regeneration necessitates.

Less careful attention seems to have been devoted to this phase of regeneration, probably because of the greater difficulty of operating upon the internal organs of small animals.

Among the vertebrates there is very little true regeneration of the internal organs. If a kidney be removed, the animal lives on and the other kidney continues to functionate for both, increasing in size for the purpose, not by the formation of new glomerules, but by hypertrophy, or increase in the size of those already present. In cases in which a kidney is damaged, by operation or disease, new tubules have been found to bud out from the pre-existing tubules and to extend for a considerable

distance either among the older tubules or in the scar tissue, but there is no new formation of glomerules, and hence no true regeneration. When large portions of the liver are removed by operation or destroyed by disease, the remaining portions hypertrophy to carry on its function, and not infrequently offshoots from the bile ducts are found extending some distance into the cicatrices, as though new liver cell columns might form, but the attempt seems to be abortive and to include only the cells of the ducts and not those of the parenchyma. The removal of the spleen is compensated for by enlargement of other lymphatic organs without any new formation corresponding to the splenic structure.

When a lung is removed or destroyed by disease, no new tissue forms, though the entrance of an unusual quantity of air may cause inflation of the undisturbed tissue—an injurious rather than a beneficial effect.

The loss of the heart or the brain is certainly, though not immediately, fatal. Life, however, is maintained under these circumstances for a very short time only in most cases. Destruction of the spinal cord results in hopeless palsy.

As the phylogenetic series is descended, the tenure of life, after such mutilations, increases, and the ability to repair damage becomes greater. Thus, in man, well authenticated cases of regenerative changes in the eye are rare, but in the triton a new lens is easily regenerated and in some of the lower batrachia young individuals may regenerate a whole eye. Still lower animals are capable of regenerating the head, including the brain and eyes, but the organs in such cases are simple and do not form counterparts of the complex brains and eyes of the vertebrates. When the heart is a simple contractile tube slowly propelling the blood through vessels not terminating in capillaries, the viscus may be dispensed with for some time, during which a new one may be provided, but when, as in the vertebrates, it is an elaborately specialized pump with complexly arranged

chambers and valves and when the somatic life is maintained solely through the circulating blood, the heart cannot be dispensed with at all.

Regeneration in Plants.

This subject is best considered under two separate headings: 1. The repair of damage; 2. The restoration of lost parts.

1. *The repair of damage done to plants* is effected through changes in the cells injured but not destroyed. The destroyed cells die, become brown and dry, and drop off. The walls of the underlying cells then become lignified or wooden and the more delicate cells below thus protected. Such changes at the cut edge of a leaf protect the remainder, which lives on in its deformed state for a long time. In the case of tubers, as, for example, potatoes, similar changes take place in the cut surfaces and thus prevent destruction of the buds which remain alive, so that cut fragments of seed potatoes may be kept for several days before planting, the buds remaining vital and beginning to grow when favorable opportunities are afforded.

The wooden stems of higher plants when superficially injured are repaired by an active growth of the living cells round about the seat of injury, forming a massive development of what is called *callus* which gradually extends over the denuded surface until it is once more entirely covered. As the callus grows, the cells become suberized and a cork-forming phellogen arises in the periphery. In the stems of gymnosperms and dicotyledons, the seat of injury is gradually surrounded and covered by a layer of tissue arising from the exposed cambium layer. While the callus is gradually spreading over the wounded surface, an outer protective covering of cork is formed, at the same time that a new cambium is forming within the callus, through differentiation of the inner layer of cells continuous with

the cambium of the stem. When the margins of the growing callus meet and close over the wound, the edges of the new cambium also unite and form a complete cambial layer continuous with the stem and covering the entire seat of injury with a new and complete cambium. The new wood formed by this new cambium never becomes continuous or coalescent with the old wood, and marks that cut deeply enough into the stem to penetrate the wood are merely covered by new wood and may be found within the stem. The ends of severed branches may similarly become so completely covered as to be concealed from view. The *callus wood* differs in certain particulars from the normal wood, consisting at first of isodiametrical cells which are, how-

FIG. 141.—Budding leaf of *Bryophyllum*. (*From Bergen and Davis' "Principles of Botany." Ginn & Co., publishers.*)

ever, followed by the formation of more elongated cell forms.

2. *The Restoration of Lost Parts.*—It is at this point that regeneration in plants and animals shows the greatest difference, for in the plant no regeneration of this kind takes place. The dissimilarities between animals and plants in the matter of growth and development throw some light upon the subject, for nearly all plants grow continuously while most animals reach maturity and subsequently cease active growth. Further, in animals the germinal matter is stored up in the gonads from which it is liberated under special circumstances, while in vegetables the germinal matter seems to be widely distributed throughout the structure and merely concentrated at the flowers and at the buds.

This wide distribution of the germinal matter makes it more easy for a mutilated plant to begin life anew from one of the germinal buds than to reconstruct the lost parts. And the results of mutilation show this to be the prevailing tendency. When mutilation is effected, a new growth starts from some undisturbed bud, whether upon leaf, leaf-stalk, bough, branch, trunk, or root, and a new formation occurs, which though it may resemble and serve the purpose of the lost part, is not an actual regeneration as is the new tail of the lizard or the new limb of the salamander. It is rather reproduction than regeneration in the plants.

The capacity for such new growth among plants varies greatly, in some cases seeming to be almost unlimited, as in the willow, of which almost any cut fragment stuck into the ground will take root or almost any kind of stump sprout, or the begonia of which even a fragment of a leaf will sometimes start a whole plant.

Reference.

Thomas H. Morgan: "Regeneration," N. Y., 1901.

CHAPTER XVII.

GRAFTING.

By grafting we understand the implantation of any portion of living tissue in the same or another position in the same organism, or in the same or a different position in some other organism.

The results of grafting vary according to the nature of the tissue transplanted, the character of the tissue into which it is transplanted, the ages of the respective tissues, the physiological importance of the transplanted tissue, the physiological necessity the organism experiences for it, the ability of the transplanted tissue to maintain itself during the period of malnutrition following the transplantation, and the blood-relationship of the respective organisms whose tissues are concerned.

The general facts bearing upon grafting apply to both the vegetable and animal kingdoms.

1. *The amputated part is immediately returned to its normal environment.*

Under these circumstances the least possible amount of disturbance is effected, and it can be imagined that if, in the replacement of the removed tissue, a sufficient amount of care is exerted in approximating the tissues, there is no essential difference between such an operation and a simple incision. Indeed the experiments of Carrel have shown that the chief difficulty is in restoring the necessary circulation, and that if this can be successfully overcome by end-to-end anastomosis of the blood vessels, whole limbs may be removed from animals as highly and complexly organized as cats and dogs, and successfully replaced or even exchanged. With the cir-

culation properly maintained, nothing more than simple healing is required to restore the usefulness of the part or member. When the tissue fragment is too small to permit of vascular suturing and must temporarily derive its nourishment by imbibition from the surrounding tissues, it becomes more difficult to effect transplantation of considerable masses. Before Nature can provide new vessels for maintaining it, the replaced tissue commonly dies and undergoes mortification. Tissues provided with free capillary plexuses most easily survive, provided they are not composed of highly specialized and easily damaged elements. In injuries of the human body large fragments of the facial tissues torn loose, but not entirely away from their attachments may be successfully replaced if not seriously infected. Fingers almost severed or torn away may be replaced, and in a few cases fingers entirely cut off have been replaced, carefully sutured, and have successfully united. There is, however, no certainty about the results in such cases, and the surgeon congratulates himself and his patient when such operations terminate in recovery. An extracted tooth restored to its socket will again grow fast and become as good and useful as before, though its nutrition is usually imperfect. New blood vessels grow into the pulp cavity, new nerve fibres find their way into it, and the restoration is fair.

Among the higher plants, the amputation and careful replacement of parts in such a cautious manner as to secure continuity of the vascular bundles is usually followed by the continued life of the graft, precautions being taken to provide artificial support until firm union of the fragments has been secured.

Among the lower orders of animals grafting becomes correspondingly easier without vascular suture. Thus when the tail of a tadpole or the leg of a salamander is removed and then replaced, some means being provided for holding the parts in place, union readily takes place and the usefulness of the part is restored.

In these cases the age of the animal experimented upon plays an important part in the success of the experiment, better results being obtained with larval than with adult organisms.

Earth-worms cut apart and then stitched together readily unite, and by cutting parts from several worms and stitching them together unusually long worms can be made, or by cutting off a few of the anterior segments and stitching them to a few segments cut from the tail unusually short worms can be produced. This reminds us that the replacement of the excised part inhibits the process of regeneration. When the leg of a salamander is cut off, a new leg regenerates as has been shown; but if the removed leg be replaced and stitched to the stump, it grows fast and no new leg develops. Similarly, if the tail of a tadpole be amputated, a new tail regenerates, but if the amputated tail be carefully replaced it grows fast and no regeneration occurs. If in replacing the tail the work be done carelessly so that the coaptation of tail and body be imperfect and a part of the stump left unprotected, the tail may grow fast, but from the uncovered part of the stump a new tail grows, so that the animal becomes provided with two such members.

When the anterior twenty segments and the posterior twenty segments of an earth-worm are amputated, the former regenerates all the necessary remaining posterior segments; the latter all the necessary anterior segments, and the middle portion, all necessary anterior and posterior segments, so that three complete worms eventually form. But if the anterior twenty segments are stitched to the posterior twenty segments, the two portions grow together, no intermediate segments are regenerated, and a short worm is formed and remains short.

Many experiments with interesting results along this line were made by Joest, who found that the "satisfaction of physiological necessity" did not seem to be the key to the situation, seeing that there might be two sets of

reproductive organs in the artificially long worms and no reproductive organs at all in the very short worms thus produced.

Should one endeavor to unite two worms by the anterior ends from which the heads have been removed, or by the two posterior ends from which the tails have been cut off, difficulties arise that indicate the strength of the force of polarity among living organisms, for though union may occur, a head often springs by re-

Fig. 142.—Heteroplastic transplantation in the earth-worm. *a*, Of tail end of another individual of the same species (Allolobophora terrestris); *b*, intercalation of mid-body region of another individual; *c*, lateral grafting of another half of another individual. (*Joest.*)

generation from the seat of union when anterior, or a tail or a head when posterior, so that the experiment eventuates in the first instance in two worms with a head in common, or in the second, two worms with three heads, or two worms with a tail in common. In posterior sutures the regeneration of the head or tail seems to depend upon the length of the amputated portions. If short, a tail regenerates; if longer, a head or a tail. Morgan doubts whether Joest is correct in thinking heads can be regenerated from combined posterior ends.

Much experimental manipulation of this kind has been performed with hydras. Trembly, Watzel, King, Morgan, and others have subjected these animals to a variety of amputations and abnormal appositions, and

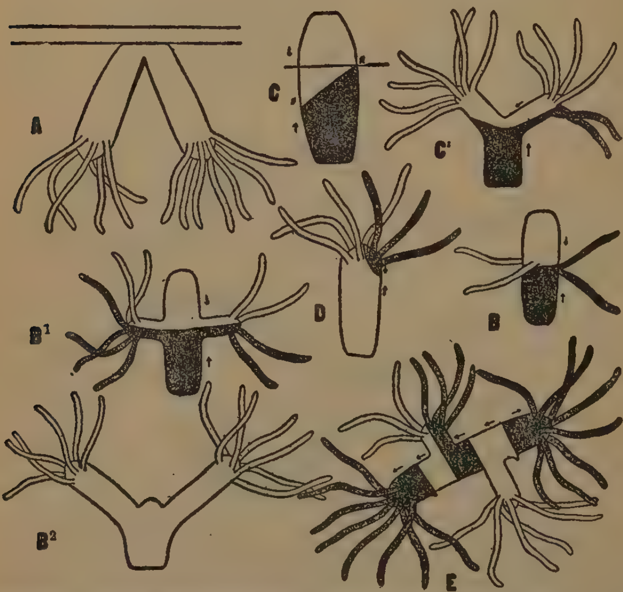


FIG. 143.—Regeneration in hydras. *a*, Hydra split in two hanging vertically downward: later the halves completely separated; B, two posterior ends united by oval surfaces; B^1, same: its regenerated two heads, each composed of parts of both pieces. B^2, absorption of one piece leading to a later separation of halves; C, two posterior ends united by oblique surfaces: later one piece partially cut off, as indicated by line; C^1, later still, two heads developed, one at M, the other at N; D, similar experiments in which only one head develops at M; E, five pieces united as shown by arrows. Four heads regenerated, one being composed of parts of two pieces. (*Morgan after King.*)

found that the force of polarity is easily set aside. Thus the organisms can be made to unite either by their oral or aboral ends. Several individuals deprived of the oral ends and tentacles can also be united and very long-bodied individuals produced. In one case

twenty-two posterior ends were united and then one of the components cut in two. In five cases a single head developed upon the aboral end of the smaller piece. When several pieces are united, a new head usually appears at the line of juncture.

Born found it possible to make transverse sections through tadpoles and then reunite them, or to unite the anterior half of one to the posterior half of the other. He also found it possible to unite two anterior portions by their posterior ends, to unite them dorsum to dorsum or ventrum to ventrum, and in the latter case it did not matter whether they were placed head to head or head to tail.

When sections passing through the organs were made and the fragments coaptated organ to organ, the organs united so that the viscera became functional; when the coaptation was imperfect, the intervals between the organs became filled in with connective tissue, and the ability of the animal to live depended upon the possibility of enough functional activity of the mutilated organs being retained.

Ullmann as early as 1902 transplanted a dog's kidney to its neck, united the renal artery with the carotid artery, and the renal vein with the external jugular vein; the end of the ureter being stitched to the skin. The exact results of this experiment are uncertain. The kidney seems to have remained active for a short time, then degenerated.

Carrel has found it possible to remove a kidney from a dog, perfuse it with Locke's solution (a physiological solution used to wash out the stagnated blood from the vessels, and so prevent coagulation) for fifty minutes, then return it to normal environment in the same animal, anastomose the blood vessels and nerves, and have the organ continue its function almost indefinitely. The following case, one of five experiments, will serve as sufficient proof: "On February 6, 1908, the left kidney of a bitch was extirpated, washed in, and

perfused with, Locke's solution, and replanted. The circulation was re-established after having been interrupted for fifty minutes. Fifteen days afterward the right kidney was removed. The animal remained in perfect health. In June, 1909, this bitch became pregnant and gave birth to eleven pups. In December she again had three pups. To-day, twenty-three months have elapsed after the operation, and she is entirely healthy."

Guthrie transplanted the ovary of a pure black hen to a pure white hen whose ovary had been removed. Subsequently the hen laid eggs, and upon being mated with a pure white cock, laid eggs that, upon incubation, produced white and black chicks.

2. *The amputated part is transplanted to a new environment in the same organism.*

Under these circumstances the conditions are somewhat different, for though the general physiologico-chemical conditions are presumably identical, the local conditions vary. It must not be imagined that the component tissues are without their mutual affinities and repugnances, for were there no such influences it is difficult to conceive how the organic integrity of the complex organisms could be retained in cases in which accident or disease bring about confusion of the normal structure. The position in which each tissue finds itself as the result of ontogenetic development is normal for it, and under normal conditions the inherited impulses of the cells may explain the preservation of the inherited ontogenetic relationship, but under abnormal conditions the usual disappearance of tissues forced into abnormal relations may have a different physiologico-chemical explanation; that is, it may depend upon antagonistic actions and reactions between the different elements.

Such an explanation does not suffice in itself, for it is only possible for any fragment to survive transplantation when an adequate source of nutrition can be found which makes it almost essential that the transplanted

tissue in order to survive must be of a quality that can retain life in spite of this serious handicap. Few tissues are so tenacious of life, and hence very few survive transplantation. Even in those cases in which the implanted tissues can be histologically recognized after an interval of months, they are found to be decadent, and in practically all cases they are destined to disappear.

It might be supposed that the vitality of the embryonal tissues under the conditions of transplantation would exceed that of the adult tissues because of their greater cellular activity, general capacity for growth, and ability to live upon imperfectly distributed nourishment, and this is true for it is quite possible to effect successful transplantations in such embryos—salamander larvæ and tadpoles—as can be submitted to investigation, though among higher vertebrates—reptiles, birds, and mammals—it is impossible.

But some cases of extensive transplantation succeed. When the nose is lost through accident or disease, surgeons sometimes build up a new nose out of tissues obtained from the patient's finger. The tissue of the face is denuded of its skin over an area of appropriate size, the surface of the chosen finger is likewise denuded, and the two stitched together. Bandages are then applied so as to hold the hand immovably in place until firm union has been established and until the tissues of the finger receive some new vessels from the face through the cicatrix. When the surgeon feels confident that this has been effected, the finger is cautiously amputated, and its tissues so manipulated that a semblance of a nose is produced. The operation commonly fails because of the great difficulty of retaining the finger immovably in position and because the new blood supply afforded the digital tissues by the facial vessels is apt to be inadequate.

In plastic operations of this and similar kinds, where cutaneous and subcutaneous tissues are transplanted, the tissues do not in the strict sense find the environ-

ment changed; that is, the fibrillar tissue meets fibrillar tissue, the adipose tissue meets adipose, and the derm meets derm.

The more heterotropic the transplantations, the less the probablilty of success. Transplantation is not much practised in human surgery, but enough experiments have been performed upon the lower animals in the laboratory to hold out considerable hope of future success. It was found by Hunter and Duhamel that the spur of a young cock could be successfully transplanted to its comb where it continued to grow and eventually attained its full size.

Ribbert transplanted the mammary gland of a guinea-pig a few days old to a position upon its head where the graft took well without absorption. The animal grew up and subsequently bore young, and it is interesting to note that the transplanted mamma secreted milk during the period of lactation.

Kocher, in 1883, transplanted thyroids in dogs with a certain amount of success; and Schiff, in 1884, obtained temporary benefit and the prevention of cachexia strumipriva in human beings by grafting thyroid tissues after removal of the thyroid gland for disease.

Von Eiselberg (1892) transplanted one-half of a cat's thyroid into its abdominal wall, waited until the wound had healed, and then transplanted the other half into the abdominal wall or cavity. The animal bore the operation well and lived on, the grafts remaining. When the grafts were later excised, tetany quickly developed, and the animal died. These experiments show that the thyroid is able to persist and functionate in a new environment.

The experiment has since been repeated many times, and it is now certain that the transplanted thyroid can remain functional during the entire remainder of the animal's life.

The success or failure of the transplantation seems to depend in large measure upon the physiological necessity

for the transplanted tissue. Thus, if a fragment of the thyroid is transplanted and the greater part permitted to remain in its normal position, the graft is apt to suffer absorption—apparently because it is not physiologically necessary. The absence of the physiological necessity probably explains many failures in transplanting thyroid tissue.

Knauer and Grigorieff performed many experiments by transplanting the ovaries of rabbits to new situations in the abdominal cavity and found that though the central portions of the transplanted organs usually underwent necrosis and were replaced by fibro-connective tissue, the superficial layer containing the follicles and ovules escaped destruction so that the function of ovulation was not affected. Three of the rabbits whose ovaries had thus been transplanted subsequently became pregnant, so that it appears that the ovules liberated into the abdominal cavity found their way to the Fallopian tubes and uterus.

Morris, in removing the ovaries and tubes from a human patient, grafted a portion of one of the removed ovaries upon the stump of one of the tubes. This graft took, and the patient later became pregnant.

Skin grafting has become a frequent and useful surgical method for facilitating the restoration of the dermal covering in extensive ulcerations such as follow superficial burns, etc. The grafts can be taken from any part of the patient's body and need not be large; in fact, a number of small grafts seem quite as useful, if not more so, than the transplantation of considerable portions of skin. In these cases, the superficial layers of the epiderm are useless as they have no longer sufficient vitality to permit them to multiply; any transplanted subcutaneous tissue is likewise useless, as it is absorbed. The essential portion comprises the rete mucosum whose cells have great tenacity of life—they may be kept alive in salt solution for ten days or two weeks—become amœboid in the new environment, and by their multi-

plication and rearrangement form the new epithelial covering.

Certain of the mucous membranes are also able to survive transplantation, and good results have followed plastic operations in which fragments of tissue from the mouth have been used to assist in the restoration of destroyed conjunctiva.

3. *The amputated part is transplanted to another animal or plant of the same kind.*

Under such circumstances the new environment to which the graft is transplanted differs from that of the autoplastic grafts in so far as the physiological conditions of two individuals may differ. As has been shown in the chapter upon Blood Relationships, the chemical and physiological conditions among individuals of the same species are usually, but not necessarily, identical. When they happen to differ, the grafts may fail exactly as when the grafts are heteroplastic.

Were it not for physiologico-chemical variation, this form of transplantation might be looked upon as the future hope of surgery, for Carrel has shown its extraordinary possibilities. Thus he has removed the kidneys of a cat and replaced them by the kidneys of another cat. The animal recovered from the operation and lived on in apparent health for some time. He has also transplanted a limb from one dog to another dog, and removed most of the tissues from one side of the face of one dog to the corresponding situation upon another dog.

These results justify the hope that the time may not be far distant when normal kidneys from a normal person killed by accident may be implanted into the body of another whose kidneys are diseased, and that a part of a limb amputated for traumatic injury or taken from a person suddenly killed by accident may be used to supply a limb needed by some other person whose member is lost through disease. Indeed, a knee-joint has already been thus transplanted from one man to another with success.

The difficulties in the way of blood-vessel anastomosis have been overcome, but the physiologico-chemical difficulties remain, and when these experimental transplantations are carefully scrutinized it is found that sooner or later the experiment animal is apt to die because of some condition referable to them. This is well exemplified in the transplantation of a cat's kidney by Carrel and Guthrie. One kidney of a healthy cat was removed and replaced by the healthy kidney of another cat. The animal recovered perfectly from the operation and lived about a year, when her previously undisturbed kidney was removed. After this operation she died in a few days with the usual symptoms of renal insufficiency. Upon examination with the microscope it was found that the ingrafted kidney had suffered histological changes that made it unable to functionate. It is also exemplified in Carrel's case of successful transplantation of both kidneys of a cat where it was subsequently found that the aorta and blood vessels had undergone an extraordinary calcification unlike anything previously known to take place in cats, and in some way directly or indirectly referable to the changed physiological conditions associated with, or following the operation.

It is not uncommon for a person to donate a sound front tooth to another whose tooth is extracted as worthless. Such a sound tooth may be implanted in lieu of that lost, grows fast, and remains useful for a long time. Here, however, the conditions are somewhat different, for the tooth implanted, though it remains in place and is firmly attached and functionally useful, is commonly a dead tooth and would quickly slough away if it were soft tissue. What applies to the recently extracted tooth applies equally to teeth extracted long before or to teeth soaked in antiseptic solutions or to bits of ivory fashioned into resemblance to teeth or to artificial teeth made of bone. All such grow fast and remain useful for considerable lengths of time, according to their

power to resist the external forces with which they have to contend.

The less imperative the nutritional requirements of any tissue, the more apt it is to withstand absorption in the new environment. While it persists, new tissue may grow in and about it so that when its final disappearance takes place it may not be missed. In some cases the transplanted tissue survives exactly as in autoplastic operations. Thus it is that in Carrel's experiment upon the replacement of a blood vessel by the employment of a part of a vessel from another animal, the transplanted fragment is able to perform its function even though it be kept on ice or otherwise for some days before being put in place.

The inherent vitality of any tissue has something to do with its ability to persist after transplantation, the differences in different tissues being shown by the experiments of Ribbert who transplanted a variety of different tissues to the lymph nodes. Epithelial cells so transplanted shortly died; fragments of salivary glands persisted for a longer time, the glandular cells changing to a cuboidal type, and the duct epithelium becoming flat; liver tissue so transplanted underwent a central necrosis, but the surface remained alive for some weeks until the epithelial cells were destroyed by the compressing effect of the connective tissue; kidney tissue was so transformed that the cells of the convoluted tubules came to resemble those of the straight tubules and the tissue to resemble that of the kidney of chronic interstitial nephritis, after which it was gradually absorbed; when the skin was transplanted in such manner that both the epiderm and cutis were included in the graft, the cells continued to be nourished by their subjacent tissue and spread out until they lined the space into which the tissue was transplanted and a cyst was formed. The transplantation of connective tissues sometimes fails, sometimes succeeds. The softer the tissue, the sooner it is absorbed; the denser the tissue, the longer

it persists and the more likely is the graft to grow. Thus transplanted fragments of perichondrium and periosteum not infrequently remain and produce new cartilage and new bone. The formation of new bone by the periosteum can only be effected, however, when the cells have some bony tissue to work upon, so that if it is desired to produce bony formation by transplanted periosteum, it is necessary to add fragments of bone, preferably fragments to which the periosteum is already attached.

Morris successfully grafted a part of an ovary from one woman upon the uterine wall of another whose ovaries, being diseased, were removed. The patient subsequently menstruated, showing that the graft not only lived, but performed a vicarious function.

In surgical skin grafting it is not unusual for one normal person to donate some of his skin to supply another with needed integument. Just as in autoplastic grafting, such grafts usually take, though whether the newly acquired skin persists or is gradually absorbed and replaced by skin of the patient's own development is a question, for interesting changes take place in the graft.

Thus when the skin of a negro is grafted upon a white person, it remains for a time unchanged, then either loses its pigment or is thrown off by a new white skin that develops beneath it. Loeb found that when skin from a colored guinea-pig was transplanted to an albino, it eventually lost its color and, *vice versa*, when the skin of an albino was transplanted to a colored animal, it became pigmented in the course of time. Here, again, we cannot be certain that the transplanted skin persists. It may be imperceptibly destroyed and replaced by the gradual growth of the normal skin of the animal.

The transplantation of embryonal tissues is not different from that of adult tissues. Fischer transplanted the leg of an embryo bird to the comb of a cock or a hen, and

found that it grew fast and appeared like a successful graft, but changed after a few months, degenerated, and was cast off.

Thus it appears that with the exception of those cases in which the organism as a whole experiences the "physiological necessity" for the engrafted tissue, the general tendency is for the graft to slowly change and disappear.

4. *The amputated part is transplanted to another animal or plant of a different kind.*

Here we are confronted by the theoretical and practical difficulties arising from the physiologico-chemical divergences existing among different species, genera, families, orders, phyla, etc. In most cases these can be prejudged by the anatomical differences, but there are exceptions.

From the facts at our disposal we are now able to state that the closer the blood-relationship of the organism furnishing the graft and the organism receiving it, the more probable the success of the experiment.

The experiments thus far reviewed have shown that very slight differences, even such as arise among individuals of the same species, may interrupt the successful progress of tissue implantations and suggest that the greater differences between individuals of different species may entirely prevent them. Let us see how these theoretical suggestions are borne out by the facts obtained by experiment.

We have already seen that hydras are susceptible of experimental manipulations of many kinds and can be successfully grafted together in many different ways. When the conjoined hydras are of different species, however, the results are different; thus Wetzel conjoined Hydra fusca and Hydra grisea and observed complete union in five hours. But later a constriction appeared where the fragments had been united, the head-piece produced a foot near the line of union, and the lower end produced a circle of tentacles. After eight days

the organism was killed for examination, and fell apart in two pieces—evidently the primary union was temporary, and being unsuccessful was followed by regeneration. In Joest's experiments with earth-worms it was found to be difficult, though possible to successfully unite Lumbricus rubellus and Allolobophora terrestris so that a single individual was produced that lived for

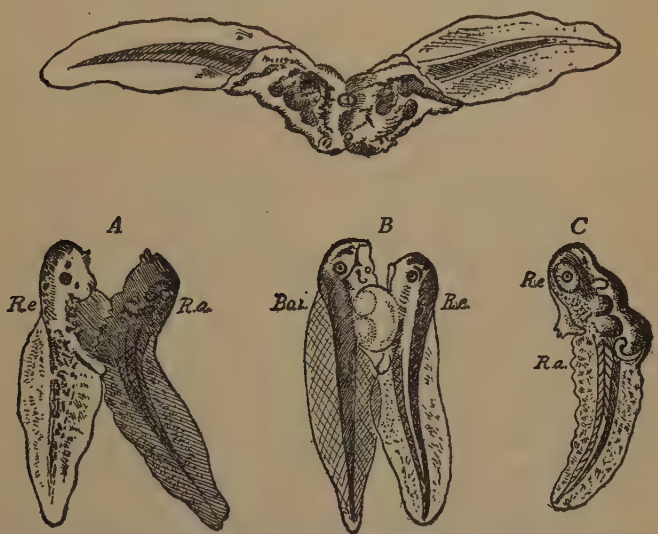


Fig. 144.—The upper figure shows two tadpoles of Rana esculenta conjoined by the dorso-cephalic surfaces.

In the lower series *A* shows Rana esculenta and Rana arvalis successfully grafted upon one another; *B*, Bombinator igneus and Rana esculenta successfully grafted, and *C*, the anterior half of Rana esculenta successfully engrafted upon the posterior half of Rana arvalis. (*Redrawn from Born.*)

eight months. Each piece is said to have retained its specific characteristics without modification.

Born, in his experiments upon tadpoles, found it possible to unite parts of animals of different species, and even of different genera; thus in one experiment he was successful in securing a union comprising an anterior half of Rana esculenta with the posterior half of Bombi-

nator igneus. After ten days, however, pathological conditions were observed and the animal was killed for further and minute study.

Another combination consisted of an anterior part of Rana esculenta and a posterior part of Rana arvalis and lived for seventeen days. Each half in both of these experiments retained its specific characters, though the circulation was common.

Harrison had still better results for, having compounded an organism of portions from Rana viresceus and Rana palustris, he was able to keep it alive until it changed into a frog, each half of which continued to show its own specific characters.

The results of transplantations effected in the higher animals are usually what might be predicted. The implanted part, if superficial, sloughs off; if deep, is absorbed Bert transplanted the tail of a white rat to the body of Mus decumanus where it remained alive; he failed when he tried to graft the tail of a field mouse upon a rat, and he had no success in his attempts to graft the tail of a rat upon the body of a dog or a cat.

As has been shown, when the skin of a negro is grafted upon a Caucasian, the pigment in the skin disappears, and eventually all trace of the graft is lost if it is not exfoliated *en masse*.

The transplantation of sheeps' thyroids into human beings in cases in which the thyroid is functionless has been performed with temporary relief, but absorption of the implanted tissue usually takes place even though the "physiological necessity" that is favorable to successful grafting seems to be present.

For many years pathologists have been industriously experimenting in the hope of arriving at some definite knowledge of the nature and cause of tumors. Being unable to apply the cultivation methods with success, and still expecting to find an infectious agent by which to account for these formations, they made many series of experiments by implanting fragments of tumors

derived from human beings into various tissues and cavities of the lower animals. The literature upon the subject is large and, when, reviewed, shows that great ingenuity and the utmost precaution have been employed that the implantations should be made under the most favorable conditions. Shattuck and Ballance, in order that nothing might be neglected that would contribute to success, even went to the length of introducing entire human mammary carcinomas (cancers) into the abdominal cavities of sheep and other animals. In every case, irrespective of the precautions, such tumor transplantations failed, and the conclusion was about reached that no tumor tissue of any kind could be successfully transplanted, when Hanau, in Weigert's laboratory, came into possession of a rat with a squamous cell carcinoma of the vulva, which he transplanted to other rats. To his and everybody's surprise these grafts grew, developed into tumors, behaved like spontaneous tumors, and caused the formation of metastatic tumor nodules in the lymph nodes. The experiment was for a long time conspicuous because of its exceptional results; then Jensen transplanted a tumor of a white mouse to other white mice, and was successful. The solution of the problem was eventually found in the homologous and heterologous nature of the transplantations. Heterologous grafting results in the disappearance of the graft by absorption; homologous grafting—transplantation of the tissue to other animals of the same kind—may be successful, and many investigators in different parts of the world have since been able to achieve and continue the homologous transplantation of mouse and rat tumors for indefinite lengths of time through hundreds of generations. Unfortunately, these successes have not yet thrown as much light upon the etiology of tumors as they have on the matter of blood relationship and tissue affinities. We have confirmed the fact that the tissues of different animals will not agree, but we have not learned the nature of tumors.

The question may be asked why the tumor tissue behaves differently from the normal tissue when transplanted, for we remember that even in the homologous and autoplastic transplantations of normal tissues the grafts are usually subject to decadence, death, and absorption. The answer seems to be found in the abnormal impulse of growth that characterized the tumor tissue and stamps it as such. It is tissue that would

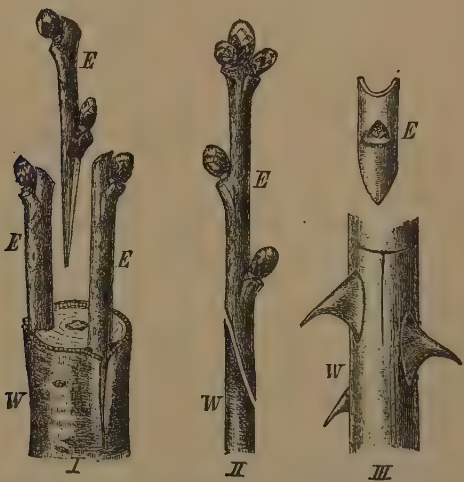


Fig. 145.—Different modes of grafting: I, crown grafting; II, splice grafting; III, bud grafting; *W*, stock; *E*, scion. (*Strasburger, Noll, Schenck, and Karsten.*)

grow unrestrictedly in its normal environment, and continues to do so when transplanted.

When we come to consider the conditions of successful grafting in the vegetable world we find that with certain exceptions they form a parallel with what has already been found in the animal world. That is, their success or failure depends chiefly upon the blood relationship of the plants concerned, though this restriction is not so closely defined as among animals. Plants of the same species can, other things being equal, easily be

grafted upon one another; plants of the same species, but of different varieties can usually be grafted one upon the other; plants of different species can sometimes be grafted one upon the other; plants of different genera can rarely be drafted upon one another, and after the generic line is past, attempts made to graft individuals of different families and orders, invariably fail.

Grafting among plants has been practised from antiquity. How the idea originated or why it was originally practised is unknown. To grafting, however, the ancients attributed results of kinds not borne out by modern scientific examination. Indeed, they seem to have believed it possible to graft almost any kind of plants together, and thereby to be able to attain to almost any desired result.

Grafting as practised by horticulturalists consists in removing a plant or a part of a plant, which is known as the *scion*, from its own trunk, stem, or root, and transferring it to another trunk, stem, or root which is known as the *stock*.

It has a very useful function in that it enables the operator to make use of easily cultivable stocks for the purpose of supporting difficultly cultivable scions. Thus, many of the luscious fruits are with great difficulty reproduced from seeds and many of the most beautiful flowers, being hybrids and infertile, cannot be raised from seeds and so would be lost were it not possible to propagate them either by slipping or grafting. The grafting of such plants also removes the risk of sporting and reversion that would undoubtedly occur if seeds of the fertile kinds were alone depended upon for their propagation. Slow-growing fruit trees that might not bear fruit for eight or ten years can be made to bear in one or two years by grafting them upon already well-grown trees of inferior quality.

The stock that furnishes the roots is derived from one plant, the scion that will bear the fruit is derived from another and usually superior plant, Will the sap ascend-

ing from the inferior stock into the superior scion effect any change in it, or will the returning sap from the scion descending into the stock modify it? In the event of the scion's being but one of many branches of the same plant, will the products of the scion descending into the stock and then returning to the other branches modify them?

It seems difficult to get at the exact facts. As has been said, the ancients believed in these modifications and laid great stress upon them. Some modification would be consistent with what has been found in certain cases of grafting among animals, as when the graft of negro skin becomes white by removal of its pigment, etc., not with others, as the retention of their relative specific characteristics by the anterior and posterior halves of a frog developing from a tadpole composed of halves derived from different individuals of different species.

The subject has been carefully considered by Daniel, who concludes that, "To say that no variation takes place in the graft is the mistake of the moderns; to believe that variation is constant, regular, and capable of any modification is the error of the ancients. The truth is to be found between these two equally exaggerated opinions."

As the result of his survey of the subject and of his own interesting experiments, Daniel came to the conclusion that "the graft does influence the general nutrition of the plant, and that its influence is manifested:

"1. By modifying the dimensions of the vegetative apparatus of the subject and of the graft.

"2. By modifying the taste and the size of the edible parts, their chemical composition, and the time of their appearance upon the plant.

"3. By modifying the rapidity with which the reproductive organs appear upon the graft.

"4. By modifying the relative resistance of the two plants to parasites and to external agents.

"The physiological copartnership seems to be entered into upon restricted lines. The general structure of the scion and the stock remain unchanged: each has its own

forms of tissues, its own mode of secondary growth, its own formation of bark, and maintains its strong individuality."

Strasburger points out "that the scion and stock do exert some influence upon one another, for when annual plants are grafted upon biennial or perennial stocks, they attain an extended period of existence." He also adds that "in special cases they do mutally exert, morphologically, a modifying effect upon each other (graft hybrids)."

McCallum gives a number of interesting examples of modifications in scion and stock following grafting. "In the leaves of *Epiphyllum* are found certain albumen bodies not found in the leaves of the related plant *Peireskia.* Mitosch grafted Epiphyllum scions upon Perireskia stocks, and in the leaves which subsequently developed upon the latter found similar bodies."

The most interesting graft-hybrid, and the only one it seems worth while to mention, is the Cytisus adami, which is a most striking example of what may happen when grafting is successful. The Cytisus vulgare is a large tree bearing racemes of yellow flowers; Cytisus purpureus a shrub of small size bearing racemes of small purple flowers. In 1826, J. L. Adam tried the experiment of grafting the latter upon the former and produced a surprising hybrid which grew into a large tree upon which appeared large numbers of the usual yellow racemes of Cytisus vulgare, large numbers of reddish racemes of equal size, and, what was most peculiar, distributed over the tree like gay parasites, there were groups of small boughs upon which were numbers of the small purple racemes of Cytisus purpureus. Presumably such an effect could only be brought about through a partial fusion of the protoplasts of stock and graft in the callus formed during the healing of the graft wound. Interesting graft-hybrids have also been produced by Winkler.

References.

Thomas H. Morgan: "Regeneration," N. Y., 1901.

C. C. Guthrie: "Heterotransplantation of Blood Vessels and Other Studies." Dissertation, Chicago, 1907. "Science," xxiv, July, 1909.

G. Born: "Ueber Verwachsungsversuche mit Amphibienlarven." Archiv. f. Entwickelungsmechanik der Organismen, 1897, iv., 349.

Alexis Carrel: "Transplantation in Mass of the Kidneys." Journal of Medical Research, 1908, x., 98.

Alexis Carrel: "Results of the Transplantation of Blood Vessels, Organs, and Limbs." Jour. Amer. Med. Asso., li., No. 20, Nov. 14, 1908, p. 1662.

C. C. Guthrie: "Survival of Engrafted Tissues." Jour. Amer. Med. Asso., March 12, 1910, liv, No. 11, p. 831.

C. C. Guthrie: Survival of Engrafted Tissues: Ovaries and Testicles." Jour. of Experimental Medicine, 1910, xii., 269.

CHAPTER XVIII.

SENESCENCE, DECADENCE, AND DEATH.

Ernest Thompson Seton has done much through his wild-animal stories to acquaint his readers with the tragic circumstances with which the lives of the wild creatures usually terminate, and has thus brought them to understand the "struggle for existence." In spite of the appalling number of unfavorable conditions to be overcome, enemies to be fought, parasites to be endured, infections to be survived, enough living things manage to grow old to show us that for each kind there seems to be a certain age limit beyond which survival is impossible because of internal changes resulting from the inevitable anatomico-physiological wear and tear. These changes are best known in man and the domestic animals, for among the wild creatures they subject the individual to insuperable handicaps in the struggle for existence.

We are accustomed to think of living things as mortal, and it is difficult to escape this conviction. Living things as individuals are mortal, but the germ-plasm is immortal and continuous.

Unicellular organisms whose multiplication takes place by fission, and whose individuals periodically rejuvenate their substance by conjugation, escape old age. There seems to be no reason apart from accident why any of them should die.

The same obtains among such multicellular organisms as multiply by gemmation. It is the substance of the parent of which the offspring is formed, and the ancestral substance is present in every individual. The condition is not materially altered when the sexual mode of repro-

duction is reached, for the gametes derived from the parents mingle their substance in the zygocyte or fertilized ovum and form the starting point of the new generation and the germ-plasm universally pervades the species and is handed down from generation to generation.

The soma-plasm that grows about the germ-plasm and subserves the purpose of transmitting it, grows old and dies, but before that time the germ-plasm is usually transmitted to a new generation by which it is transmitted to other individuals, and so on forever.

"The germ-plasm is like some great legacy: the trustees grow old and die, but the fund goes on forever." *The individual is but an incident in the life of the germ-plasm.*

The soma develops through activities contained in the germ, all its conduct is predetermined in the germ, the method by which the germ-plasm is to be transmitted to a new soma is predetermined in the germ, and the time of the decadence of the custodial soma is predetermined by the germ.

The more complexly differentiated the soma becomes, the more difficult it is to sustain and the privilege of conjugation by which rejuvenation of the cells seems to be effected being reserved for the germ-plasm alone, the decadence of the soma becomes inevitable.

The longevity of the soma-plasm is extremely variable and the laws by which it is determined are unknown. Among different living things, great differences in longevity obtain. Some insects live but days or even hours; the great sequoia trees live for thousands of years.

But even among closely related living things there are great differences in longevity. The sequoia trees live for thousands of years, but some of the firs become decadent in twenty years. Ravens, crows, and parrots live from fifty to a hundred years, but most other birds only one or two decades.

The whole subject of longevity is vague and few principles regarding it can be formulated. Those creatures

seem to live longest that are longest in arriving at maturity, but there are such striking exceptions that one hesitates in making this a rule. For example, certain ants that reach maturity in a few weeks are known to live several years, while a species of Cicada remains a subterranean nymph for seventeen years and then

FIG. 146.—Hair about to become gray. Chromophages transporting the pigment granules. (*Metchnikoff.*)

emerges from the ground to enjoy but a few days of adult life.

Too little attention has been paid to the phenomena of senescence to give us any clear understanding of them. We are even uncertain how many of the changes found in aged human beings are purely senile and not the results of antecedent ailments. If we view the senile state from the point of view of wear and tear, we are not infrequently confronted by the paradoxical

discovery of an extremely aged person in whose dead body the supposedly characteristic changes are absent.

Two *savants* have devoted particular attention to the phenomena of senescence. Charles Sedgwick Minot refers all of the senile changes to cellular transformations which he calls "*cytomorphosis.*" His views are summarized in the following four laws:

1. Rejuvenation depends on the increase of the nuclei.
2. Senescence depends on the increase of the protoplasm and on the differentiation of the cells.
3. The rate of growth depends on the degree of senescence.
4. Senescence is at its maximum in the very young stages, and the rate of senescence diminishes with age.

According to Minot, the completion of embryonal development begins the period of senescence which progresses rapidly as the individual grows into an adult, and more slowly thereafter.

Elie Metchnikoff refers the senile changes to the increasing activity of phagocytic cells by which the less active somatic cells are slowly destroyed.

There seems to be truth in both doctrines. The more completely the cells are differentiated and specialized, the less independent and less vital they become and the more readily they fall into decadence.

Let us now examine the human body to determine what may be regarded as the usual signs of old age and in what manner they contribute to final dissolution and death. Be it understood, however, that the order in which the recognized conditions are considered is not by any means the necessary order of their occurrence. Indeed it seems impossible to determine the exact chronology of the changes as almost any of the important disturbances may establish a "vicious circle" by which it may become intensified, as well as other retrogressive changes inaugurated.

With increasing age we find *atrophic changes* in all the organs and tissues of the body. This atrophy is gener-

ally characterized by loss of the cellular tissues and increase of the fibrillar tissues and is accompanied by diminished functional activity of all the parts involved.

The *heart* is usually small, its muscle brown and tough, and the subepicardial tissue either abnormally fatty or quite devoid of adipose tissue. The muscle cells are usually excessively pigmented.

The *lungs* usually show more or less widespread emphysema. This probably depends upon the loss of the elastic tissue and the permanent overdistention of the air vesicles in consequence. The changes usually occur first at the sharp anterior edges and apices of the lungs, but may be universal.

The *stomach* may be quite small, the glandular tubules diminished in number, the muscle thinned, and the fibrillar tissue increased. The loss of the glandular tissue impoverishes the enzymic content of the gastric juice as well as diminishes its quantity; the disturbance of the muscular tissue weakens the peristaltic action, and not infrequently the muscle yields to the distention of gaseous contents, when fermentative changes occur through deficiency of the gastric juice.

The *intestinal* walls are thinned, and many of the rugæ of the jejunum and upper ileum obliterated. The colon may be contracted and thinned or may be dilated and still more thinned.

The *liver* usually shows brown atrophy. It is small in size, pigmented, and indurated. The quantity of bile is diminished, and the urea forming and glycolytic functions disturbed.

The *pancreas* usually shows more or less atrophy of the secreting structure, increase of the interstitial tissue, and atrophy of the bodies of Langerhans. These bodies are not infrequently the seat of hyaline degeneration.

The *kidneys* show more or less atrophy of the parenchyma and increase of the interstitial tissue, and in addition commonly show localized atrophic areas referable to changes in the blood vessels. By comparing

a large number of kidneys of various ages, from one year or less up to ninety-nine years, Walsh has found that the proportion of connective tissue between the ducts at the apical portion of the pyramids regularly increases with age.

The *muscular tissues* are everywhere atrophic and show a distinct increase of fibrillar tissue, which accounts for the general muscular weakness of the aged. As these changes are not confined to the voluntary muscles, but also affect the cardiac and involuntary muscles, they explain the general cardiac weakness and the inactivity of the alimentary canal. They also explain the toughness of the flesh of old animals. The loss of muscular tone is also responsible for the relaxations of the dorsal muscles by which the altered carriage of the aged is partly brought about, and the loss of tone in the abdominal muscles explains the frequency with which umbilical and other herniæ occur or enlarge in the aged.

The *bones* show pronounced atrophic changes. The anatomical landmarks indicative of muscular attachments, etc., well marked in youth, gradually become obliterated and the surfaces smoothed over. The cranial sutures become obliterated and the bones united. The thinner processes of the bones are gradually absorbed. This is perhaps best exemplified by the alveolar processes of the maxillary bones whose atrophy, accompanied by the recession of the gingival tissues from the teeth, is followed by looseness of these organs, which fall out, even if they have not already undergone decay. The loss of the teeth and the absorption of the alveolar processes cause an approximation of the nose and chin, characterized as the "nut-cracker face." In atrophy of the bones the too busy osteoclasts misapply their energy, so that the compact layers become more and more dense and brittle, leaving the cancellous tissue insufficiently supported. Certain portions of the skeleton—notably the necks of the femurs—also tend to bend. There is also a disposition for bone to form in unusual

situations, such as between the bodies of the vertebræ and about the intervertebral discs, so that individual vertebræ become welded together and immovably fixed. If the muscles of the erector spinae group have permitted the body to drop forward, the spine may become hopelessly fixed in this curved position. It is partly through such bony changes that the height of the aged person becomes considerably reduced.

The *skin and its appendages* show well-marked atrophic changes. The first of which may be whitening of the hair. This has been found by Metchnikoff to depend upon the absorption of the pigment from the cells of the medulla of the hair by phagocytic cells—pigmentophages—through whose activity it is first transferred to the bulb of the hair, and subsequently removed altogether. With or without the loss of the color, the hair follicles may atrophy and baldness occur. Though such changes occur upon the scalp and beard and about the pubes and axilla, the hairs of the beard and eyebrows are apt to become coarse and bushy, and coarse hairs frequently appear upon the ears and elsewhere. The skin itself becomes thinned, shining, more or less transparent, and marked with brownish discolorations. The sense of touch is impaired, so that it is probable that the sensory end organs of the nerves also atrophy and disappear in part.

The *sexual organs* participate in the senile changes, those of women more early than those of men. With women the first change is physiological and is shown by the cessation of menstruation—*menopause*. This is soon followed by atrophy and cirrhosis of the ovaries, more or less atrophy of the uterus, and involution or atrophy of the mammary glands in which the glandular tissue is in part replaced by adipose tissue.

In men the atrophic changes of the sexual organs is postponed for a considerable time, so that the sexual life of a man is considerably longer than that of a woman. Eventually, however, the testes show atrophy and pig-

mentation of the cells of the seminiferous tubules and the formation of spermatozoa almost ceases. The prostate gland sometimes enlarges in old men, but in not a few aged men follows the usual rule and atrophies.

The *blood-vascular system* undergoes a general fibrosis, chiefly characterized by loss of muscular and elastic tissue. The endarterium is prone to suffer from proliferation of the subendothelial tissues and more or less obstruction. These changes may be accompanied by more or less saponaceous change followed by calcification. If calcification chiefly localizes in the middle coat, the vessels may be transformed to mineralized hollow cylinders—"pipe-stem arteries"; when it localizes in the intima, calcareous plates appear in the vessel walls. Fibroid changes cause the vessels to lose their elasticity, increase the blood pressure, throw an additional strain upon the heart, and further damage some of the viscera, especially the kidneys. If the changes are internal and obstructive, they eventuate in atrophy of the tissue to which the particular vessel distributes. Calcareous vessels become brittle and liable to fracture with resulting hemorrhage. Apoplexy, that so frequently carries off the aged, commonly results from the rupture of such vessels in the brain and the destruction and compression of the cerebral substance by the escaping blood. When the peripheral arteries are the seat of sclerosis and calcification and are consequently obstructed, the limbs are sometimes insufficiently nourished and gangrene of the extremities—usually of the toes and feet—may supervene.

The *nervous system* suffers considerably. There can be no doubt but that all of the organs of special sense are more or less embraced in the general atrophic conditions for the acuity of all these senses is usually obtunded. The vision becomes more and more dimmed, the hearing is dulled, the senses of taste and smell are enfeebled. But the central nervous system also suffers. The brain not infrequently suffers from more or less

well-defined areas of arteriosclerotic atrophy and softening. Metchnikoff has observed that in old parrots the nerve cells become surrounded by phagocytic cells—*neurophages*—that gradually encroach upon and destroy them. Such destruction of the nervous tissues inevitably results in changes in the psychic condition of the individual.

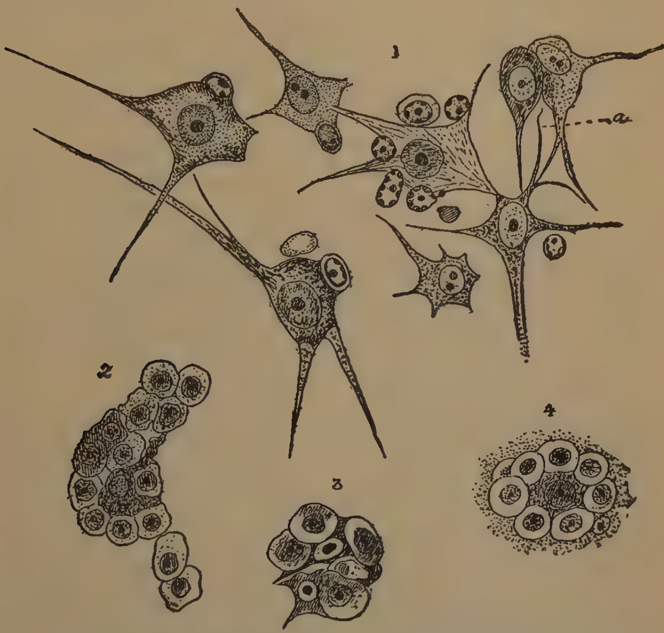


FIG. 147.—Nerve cells surrounded by neurophages—phagocytic cells—by which they are gradually destroyed. This form of phagocytic activity only occurs during old age. (*Metchnikoff.*)

These anatomical and histological changes amply explain the defective physiology of senility. The cardiac weakness and defective vessels are inadequate to provide that free circulation by which alone the integrity of the tissues can be maintained, and there is a tendency for widespread calcification to make its appearance.

It is, therefore, found in the costal and other cartilages, in the blood-vessel walls, and sometimes in other tissues.

The digestive organs being altered, the digestive functions are inadequate or defective. The eliminative organs are not only themselves defective in structure, but are embarrassed with the imperfectly transformed metabolic products by which further changes in their substance are induced. The general oxidation processes are disturbed and it is difficult to maintain the temperature, and fatigue and exhaustion supervene upon slight effort. In some cases a tendency to obesity presents itself.

The psychic conditions are adequately explained by the destruction of the nervous tissue through arteriosclerotic atrophy and softening and by the phagocytic destruction of the nerve cells. It is more difficult to explain the peculiar character of the decadent mentality, for those familiar with old people well know how acute the aroused mind may be in contrast with its usual apathy, and must have observed how much more vivid are early impressions than recent ones.

It naturally follows that such enfeeblement of the vital powers gradually causes life to hang upon a very slender thread, so that infections that might easily have been overcome in the vigor of youth are quickly fatal—pneumonia being one of the most common causes of death among the aged. A severe mental or physical shock disturbs the delicate equilibrium and the weakened heart may stop. Indeed, in cases in which the process of decadence has been slow, and the anatomical and physiological disturbances fairly uniform, no other cause for death can be assigned than the gradual exhaustion of the vital powers.

In complexly organized beings it becomes necessary to distinguish between *somatic* and *molecular* death. Somatic death refers to the death of the individual, molecular death to the death of his component cells. Among the higher vertebrates it is a distinction easy to make, but as the scale of life is descended it becomes

more and more difficult. The life of the higher animal rests upon a tripod consisting of the three fundamental functions—circulation, respiration, and innervation. These are indispensable functions, the suspension of any one of which causes somatic death in a few moments. We do not say, however, that the individual is dead until all three functions have ceased. There are other functions whose suspension is equally fatal, though the end is approached more slowly. Thus should the kidneys be removed, their arteries ligated, or their function otherwise set aside, death is inevitable, nothing can possibly save life, but the end is approached gradually and comes after much suffering through the final interruption of either the circulation, the innervation, or the respiration.

The tissues and their component cells continue to live on for some time after somatic death has occurred, the actual duration of life depending upon their individual vitality and the quantity of absorbable and still utilizable nutrient juices available.

There is great dissimilarity among the different tissues in this particular. The nervous tissues seem to die quickly; the muscular tissues preserve their contractile power for some time. The epithelial cells of the skin and of the hair follicles seem to live for some days, so that it is quite possible for the hair to grow a few millimetres after death—perhaps in some cases even more. Soon after death certain chemical changes set in and poison those cells that might otherwise survive longer. Such are responsible for the *rigor mortis* or stiffness of the muscles brought about by coagulation of the myosin.

As we descend the scale of animate life, we find a general tendency toward the prolongation of molecular life after somatic death. This can probably be explained by the differing chemical conditions in the bodies of the lower forms.

Thus in the familiar superstition that a dead snake moves its tail "till sundown," and in the tendency for

the amputated head of a snapping turtle to bite and hold fast to a stick, or in the tendency of a decapitated rattlesnake to coil and strike, we see examples of prolonged molecular or cellular animation after somatic death has occurred.

If we descend still lower, it becomes impossible to make any clear differentiation between the somatic and molecular death except by experiment. Thus, when an earth-worm is chopped to pieces, all the fragments live on for a considerable time—many days—and it is only experience with the regenerative powers of this animal that enables one to predict which fragments may, and which may not live and form new worms.

Still more interesting is the condition found in the hydra. The animal is cut to pieces, each piece draws itself together, becomes inactive and apparently dead, but after a time quite small pieces may rearrange the substance, fit themselves for further growth and may recover.

The relation of molecular to somatic life and death depends upon the degree of specialization attained by the cells and their ability to maintain more or less independence under unfavorable condition.

This is well exemplified by the behavior of plants among whom somatic life is very slightly differentiated from molecular life because of the absence of such specialized organs as those controlling the functions of circulation, innervation, respiration, and digestion in animals. Partly for this reason and partly because of the general diffusion of reproductive energy among the vegetative cells, portions of many plants cut off from the parent and placed under appropriate conditions live on, grow well, and soon renew the whole plant.

The somatic life of each individual eventually comes to an end, but the life of the germ-plasm persists in its descendants in a succession of ever-changing forms for which one can see no end so long as the physical condition of our planet continues to afford such conditions of

temperature and moisture as are compatible with life as we know it.

The death of the soma and the succeeding retrogressive and analytic changes it undergoes must not be interpreted as loss. The greater part of the surface of the earth is covered by a layer of matter composed of the products of organic decomposition which is continually utilized by new living things. As one living organism dies and disintegrates, others of different kind arise from its remains, so that the organic compounds are perpetually undergoing cyclical integration and disintegration, in which available material is worked over and over again with ever new results by new organisms arising through the energy of the immortal germ-plasm.

References.

Charles Sedgwick Minot: "The Problem of Age, Growth, and Death: A Study of Cytomorphosis Based on Lectures at the Lowell Institute," N. Y., 1908.

Elie Metchnikoff: "The Nature of Man," translated by I. C. Mitchell, N. Y., 1903. "Etudes Biologiques sur la Veilleuses," Annales d. l'Inst. Pasteur, xv., xvi., 1901-1902.

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